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TECHNICAL REPORT GL-82-2

NATURAL PROCESSES INFLUENCING TERRAIN ATTRIBUTES

Report 1

PREDICTION OF RESIDUAL SOIL TEXTURE IN HUMID TEMPERATE CLIMATES OF THE FEDERAL REPUBLIC OF GERMANY AND SELECTED ANALOGOUS PORTIONS OF THE UNITED STATES—PILOT STUDY

by

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To develop a methodology for predicting soil texture, an intensive literature review was made of the interrelations among genetic factors, natural and cultural processes, and soil formations, and a considerable quantity of pertinent data from the field and literature was collected for the Federal Republic of Germany and the eastern United States. The literature was summarized and the data shown. A total of 1309 soil profiles were examined. Every profile was classified in Unified Soil Classification System terms and 1285 of

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20. ABSTRACT (Continued).

these were also classified in U. S. Department of Agriculture terms. Each profile consisted of two soil samples, one from the 0- to 6-in. depth and the other from the 6- to 12-in. depth. The soils data were shown in tabular and graphic form representing the occurrence of soil types for given rock types (residual soils) and soil types in glacial and aeolian deposits, respectively. A tabular breakdown of soil types according to slope classes also was shown. The significant findings of the literature review and the soil-rock data were synthesized to evolve the subject methodology.

SUMMARY

A methodology was developed to permit the prediction of soil texture. The methodology was based on the premise that two geographically remote, but environmentally analogous areas, that have been similarly acted upon by genetic factors (climate, time, geology, topography, and biological activity), natural processes (residual, alluvial, colluvial, etc.), and cultural processes (agriculture, managed forests, etc.) will produce similar landform or terrain conditions. For simplicity and convenience, the scope of the study was limited to prediction of only one terrain factor, soil texture. The scope was further restricted to humid temperate climates and residual soils on a range of slopes. The methodology was developed after an intensive literature review of soil-formation principles and examination of soil-rock data obtained especially for this study. The study is regarded as a pilot study, a prelude to studies intended to develop methodologies for the prediction of all terrain parameters significant to offroad vehicle mobility, in all areas of the world.

PREFACE

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Chief of Engineers (OCE), as an initial step, or pilot study, in the development of quantitative relations among terrain and climatic factors and those natural processes that influence detailed terrain attributes affecting the operation and performance of ground-crawling equipment and support systems. The study was performed during the period July 1978-September 1980. Funding for the study was provided by the Department of the Army under In-House Research Project 4A161102AT24/A3.

Field data were collected in the Federal Republic of Germany in 1978 and 1979 by Mr. W. K. Dornbusch, Engineering Geology and Rock Mechanics Division, as a member of a team collecting terrain data for the purpose of updating the Army Mobility Model. All phases of the study were under the direction of Mr. Dornbusch, who wrote the report. A technical review was conducted by Mr. Sterling J. Knight, whose comments are gratefully acknowledged. All phases of the study were under the general supervision of Messrs. D. D. Randolph, Chief, Methodology and Modeling Research Group, and C. J. Nuttall, Jr., Chief, Mobility Systems Division. Mr. J. P. Sale and Dr. W. F. Marcuson were Chiefs of the Geotechnical Laboratory (GL), and Dr. P. F. Hadala was Assistant Chief, GL.

COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE, were Commanders and Directors of the WES during the conduct of this study and the preparation of this report. Mr. Fred R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
square miles	2.589998	square kilometres

NATURAL PROCESSES INFLUENCING TERRAIN ATTRIBUTES

PREDICTION OF RESIDUAL SOIL TEXTURE IN HUMID TEMPERATE CLIMATES OF THE FEDERAL REPUBLIC OF GERMANY AND SELECTED ANALOGOUS PORTIONS OF THE UNITED STATES-- PILOT STUDY

PART I: INTRODUCTION

Background

1. Preparedness of United States military units to function effectively in diverse world environments is a major deterrent to enemy aggression. As part of such preparedness, insight must be provided on the performance of military vehicles in the terrains in which the vehicles might be required to operate.

2. Extensive testing in recent years has produced meaningful relations between certain terrain parameters and vehicle characteristics. These relations have been incorporated into the now widely accepted Army Mobility Model, which is a mathematical, computer-compatible system for predicting the performance of any land vehicle on any terrain, when certain information is known for both the vehicle and the terrain. While the required vehicle data are easily acquired, the ideal required terrain data have nearly always demanded very expensive and time-consuming efforts by trained personnel making measurements in the given area. The acquisition of such data on a worldwide basis is clearly not practicable or economically feasible. Unfortunately, measurements of terrain parameters are currently limited in their application to the precise location at which they are measured, and the considerable quantity of good-quality terrain data already acquired (and on file) cannot be used further, unless some effective methodology can be developed whereby the data collected at one location can be applied with equal or near-equal precision to other remote geographic locations.

3. It is a fact that similar environmental conditions (climate, geology, etc.) produce similar terrain conditions in a macro sense

(hills, valleys, deserts, etc.) and it is hypothesized (but by no means yet fully demonstrated) that they also produce similar terrain conditions in a micro sense (discrete types of soils and vegetation, etc.). Accordingly, it is proposed that, fortified by the acquisition of additional pertinent data in selected areas, efforts begin to develop a methodology for predicting pertinent mobility terrain factors in remote areas, based on the hypotheses stated above and the principle of analogy.

4. It is considered that such a methodology must identify and account for the effects of all the primary and secondary genetic factors and natural and cultural processes responsible for the evolution of diverse world terrain types. The methodology should be both flexible and open-ended to permit the use of data obtained from diverse sources and to facilitate continued improvements, i.e., upgrading, in the scope, accuracy, and ease of application of the methodology. The research program to develop such a methodology must be undertaken with consideration for the necessity of establishing quantitative criteria regarding the degree of analogy between various areas, since this will vary with the quantity and quality of the data used and thus directly influence the accuracy of the final results of the methodology, i.e., the input terrain data needed for application of the Army Mobility Model.

Purpose and Scope

Purpose

5. The ultimate purpose of this and subsequent studies and reports is to develop a methodology that will permit reliable predictions of terrain parameter values pertinent to ground mobility by associating those parameters with genetic environmental factors and the natural and cultural processes interacting with those factors to generate discrete terrain units. The purpose of this methodology is to provide a genetically based mechanism by which detailed measurements of terrain parameters taken at selected sites can be extrapolated to remote areas where environmental factors are determined to be highly analogous. The specific purpose of this study was to develop such a

methodology in order to permit the prediction of only one soil parameter--soil texture--from common parent material, i.e., rocks. This study is to be considered a pilot study.

Scope

6. In scope, this study was climatically and geographically restricted to humid temperate climatic regions of the Federal Republic of Germany and the eastern United States. The Federal Republic of Germany was selected because of military interest and priority; the United States because of the ready availability of pertinent data.

7. The study was further restricted to the study of only one soil parameter--soil texture. Texture, as used in this report, is synonymous with grain-size distribution. It is also nearly synonymous with soil type as defined by both the Unified Soil Classification System (USCS) and the U. S. Department of Agriculture (USDA) soil classification system. Texture was selected as the "pilot" parameter primarily because of its relative importance, availability of data, and simplicity of portrayal.

8. Another restriction in scope was confinement to residual soils, mainly for the sake of simplicity. Glacial and aeolian soils data are included in this report but were not specifically considered in the analysis.

9. The study consists of a literature review (and documentation) of the interrelations among genetic factors, natural and cultural processes, and soil formations known to affect terrain parameters relevant to military activities, emphasizing the soil texture parameter, and a statistical analysis of soil types formed by residual, glacial, and aeolian processes on a range of slopes. Only data for the United States were used in the statistical study. The final step in the scope of this study was the synthesis of the literature review and the soil data into a methodology to predict soil texture.

10. A formal in-depth study of the exact degree of analogy existing between the Federal Republic of Germany and eastern United States was not made. However, sufficient preliminary study was made to suggest that there is, indeed, a high degree of analogy between the two areas, and occasional opportunities arose during the course of the study

to verify this. Accordingly, for purposes of this study, it was assumed that the Federal Republic of Germany and eastern United States are analogous.

11. A limited study was made to compare the soil types derived from similar origins in the United States and the Federal Republic of Germany.

General Approach

12. The general approach adopted for the development of the subject methodology was to combine the findings of a thorough literature review with a statistical examination of rock-soil data to evolve a methodology for predicting soil texture. It was recognized that such a methodology could never be completely quantitative or mechanical because of the inherent complexity of the phenomena involved. It was known that the accuracy of, as well as the precise steps to be taken in, any conceivable methodology would always depend heavily on the input data available and the knowledge, experience, and judgment of the applier of the methodology, who ideally should be a geologist. Nevertheless, it was felt that a methodology for soil texture prediction could be developed for application by, say, civil engineers with a general working knowledge in geology.

Literature review

13. The literature review consisted of the examination (and documentation of pertinent findings) of those genetic factors and natural and cultural processes that influence the formation of residual soils in the humid temperate climates of West Germany and the United States.

14. Genetic factors. The primary genetic factors controlling the evolution of soils are: (a) climate, (b) time, (c) geologic structure and lithology, (d) gross topography (relief and elevation), and (e) biological activity. These factors can be identified and evaluated in most areas from readily available, albeit generalized, source materials. Data on secondary genetic factors, e.g., (a) local topography

(topographic position, slope), (b) local weather, (c) vegetation (natural or managed), and (d) drainage, come from more detailed sources of information (if available) and permit refinements in parametric predictions, thus narrowing the overall range of variation.

15. It should be borne in mind that source materials for the determination of both primary and secondary genetic factors will not only vary from one country to another but also from one study area to another. While detailed climatic data may be available for an area, detailed data on geologic factors may be lacking. Time, while considered an important genetic factor, can never be considered in more than a general sense since numerous, sometimes unidentifiable, changes in climate have taken place during the period in which the soil was formed. Biological activity is relevant only to the upper surface of the soil where it overlies and to some extent mixes with the mineral matter. The interaction of the decaying organic matter with rainwater creates an acid, which helps to leach the sur ace horizon of certain mineral constituents. This surface layer of organic material remains essentially the same thickness since in the subject study areas chemical weathering is active during the warm months and largely inactive during the cool months. Biological activity is present largely in the forested areas but is also present to some degree in the cultivated areas since the stubble remaining after harvest is often plowed into the soil.

16. Natural processes. The primary and secondary factors influencing soil formation are all integrated by mechanisms called natural processes. These processes are active throughout the entire study area and are largely classified as depositional (constructive) or erosional (destructive). Another natural process (residual) occurs when soil is formed in place from the parent material (large rock) underlying it. There are numerous natural processes (erosional, depositional, and residual) occurring within the study areas in the Federal Republic of Germany and analogous portions of the United States. The most important of these are: (a) residual, (b) glacial (depositional), (c) aeolian (depositional), (d) alluvial (depositional and erosional), (e) colluvial (depositional and erosional), and (f) volcanic. These processes are

both active or relict, the latter having been active in the last one to three million years. They may occur singularly or in combination. The processes addressed in this report are largely residual, with subordinate interest devoted to glacial and aeolian. The residual processes are locally modified by alluvial and colluvial processes. The quantitative evaluation of all the genetic factors and natural processes in a given area is impossible; however, these variables can be dealt with objectively and thus produce a reliable estimate of the soil texture parameter.

17. Cultural processes. The manifestations of all natural processes in terrain are subject to modification by cultural processes indigenous to the area of study. Two areas, in close proximity and each the product of similar genetic factor-soil processes (i.e., theoretically analogous), may not be truly analogous. Certainly, the two areas are not analogous if, for example, one consists of an old, i.e., natural, pasture, while the other is a golf course, with many cuts and fills, subsurface tile drainage, etc.

Examination of rock-soil data

18. Rock-soil data were collected in the Federal Republic of Germany in 1978 and 1979, but only as minor adjuncts to other field programs. Because of the paucity of data, the Federal Republic of Germany was omitted from the statistical analyses to be presented later, which was confined to United States rock-soil data only. The Federal Republic of Germany data, however, were used in a limited comparison of United States and Federal Republic of Germany soils derived from the same rock types.

19. Since the source materials dealing with rocks and soil in the Federal Republic of Germany and the United States vary considerably in description and terminology, it was considered necessary to use a standard soil classification. While the USCS engineering classification (which is related to the engineering behavior of soils) was considered ideal for the purposes of this study, it was found that most data on residual soils were in USDA textural terms. Fortunately, there is a satisfactory correlative bridge between the two systems, enabling dual classification in most cases.

20. Descriptions of rocks occurring in the Federal Republic of Germany and analogous portions of the United States from available source materials were far less definitive than the soil descriptions of the same area. Since most rock types can vary significantly in their mineralogical composition, this is an obvious disadvantage to the establishment of precise rock-soil relationships. As a result, a range of soil types which may weather from each general rock type can be shown by the statistical analysis of numerous samples. Another serious drawback in establishing rock-soil relationships is the generalization necessarily occurring on small-scale geological maps. Often, several rock types with dissimilar lithologic characteristics are grouped under a single stratigraphic term and the resulting residual soil is a reflection of the combined weathering products of all of the rocks. At present, there appears to be no adequate solution to this problem other than finding more detailed maps, interpretation of large-scale air photography, or the collection of ground truth data in such areas.

21. Statistical analysis was performed for rock types and glacial and aeolian deposits for which accompanying soil data expressed in either of the two soil classification systems were available. Further statistical analysis was performed to determine the effects of slope on grain size distribution. Both the 0- to 6-in.* and the 6- to 12-in. layers were analyzed because of their relevance to vehicle mobility.

22. The textural distribution data for USDA and USCS soil types for each rock type were derived from the analysis of hundreds of samples selected in analogous regions of the United States. It is felt that the statistical approach to the determination of common rocks and associated residual soils relationships is a meaningful way of establishing soil texture variations within common rock units.

23. The approach should remain open-ended so that new data can be continuously introduced into the system. As a result, soil type

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

distributions within the various rock types will inevitably shift slightly in some cases and dramatically in others.

Terms and Definitions

24. Throughout the text of this report, a number of soil-rock and mobility terms will be used. It is necessary that these terms be defined and/or amplified to reflect the context used by the author.

Soil terms

25. Soil. Soil has been defined in a number of ways to accommodate various disciplines in which it is a factor. One of the most comprehensive is stated in the Soil Survey Manual:

> Soil is the collection of natural bodies occupying portions of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter, acting upon parent material, as conditioned by relief, over periods of time.

For the purpose of this study, the definition may be expressed purely in textural terms for the 0- to 6-in. and the 6- to 12-in. layers.

26. Unified Soil Classification System (USCS). The USCS characterizes soils on the basis of their engineering behavior in various types of construction. Soils are defined in terms of texture, Atterberg limits, and organic content (Figure 1).

27. U. S. Department of Agriculture (USDA). The USDA system is textural, being based exclusively on grain size (Figure 2). Unfortunately, as is evident in the lower portion of Figure 2, the breaks between textural classes (e.g., gravel, sand, silt, and clay) are not the same as for USCS. Since many parts of the world are mapped in textural terms, it has frequently become necessary to use the USDA system and to develop a correlation between it and the USCS. Figure 3 presents an early attempt to correlate between the two systems (the triangle), and a comparison of USCS and USDA grain sizes corresponding to the terms gravel, sand, silt, and clay. The soil-type information used in the analysis was based on data obtained from 1176

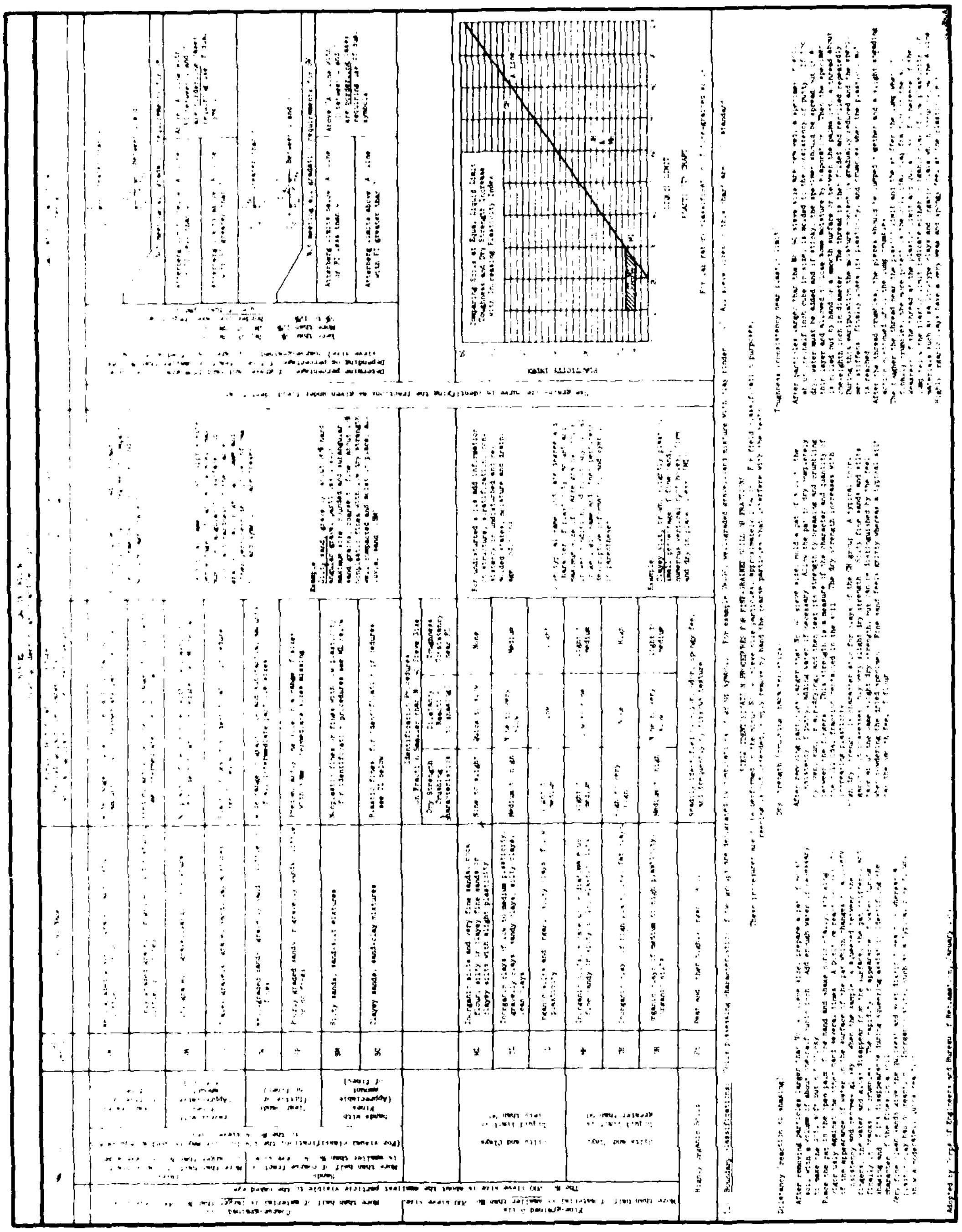
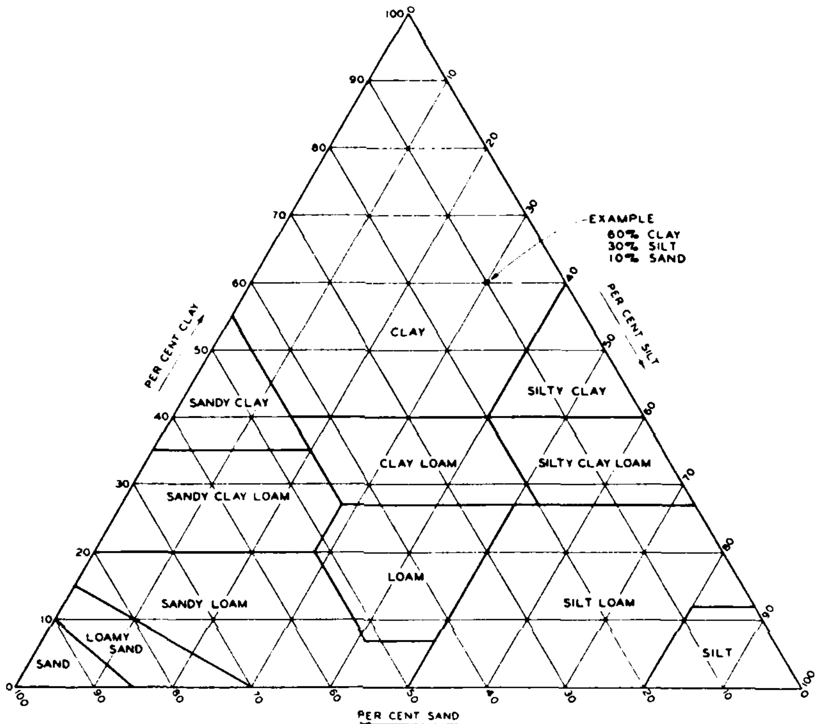


Figure 1. The Unified Soil Classification System (USCS)

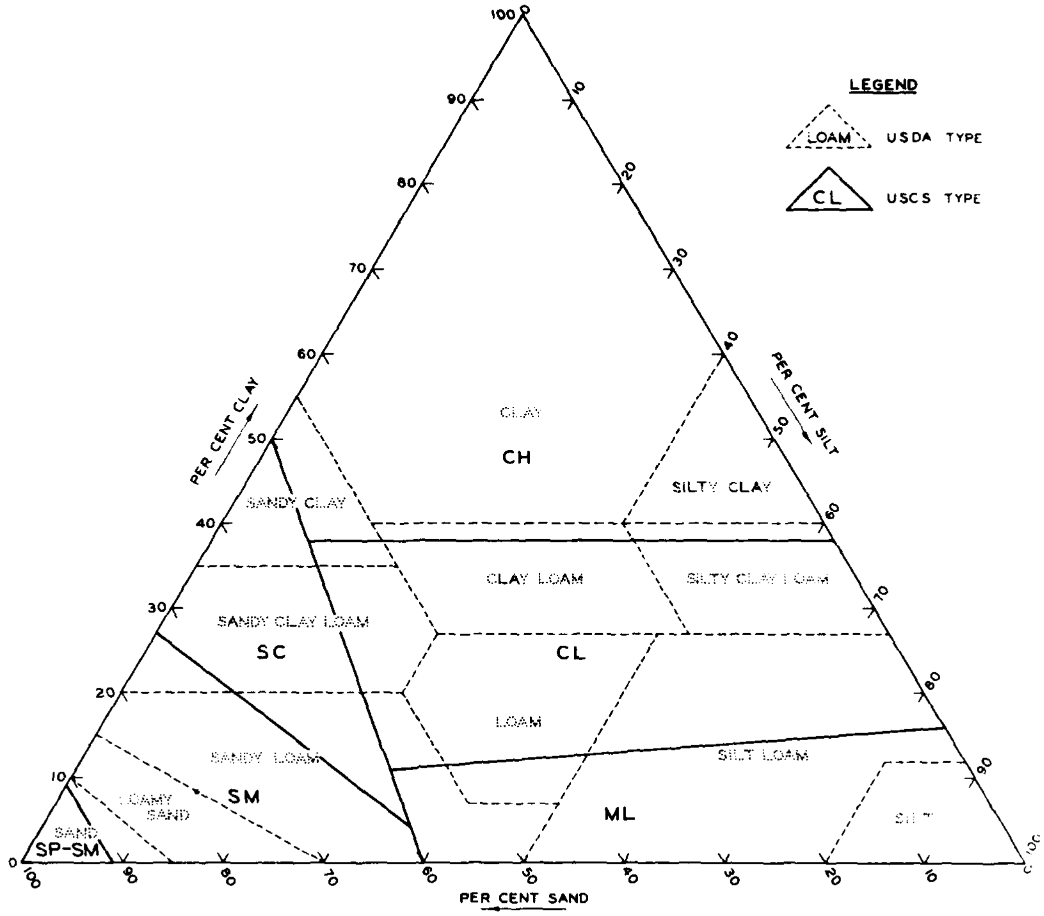


a. Textural classification

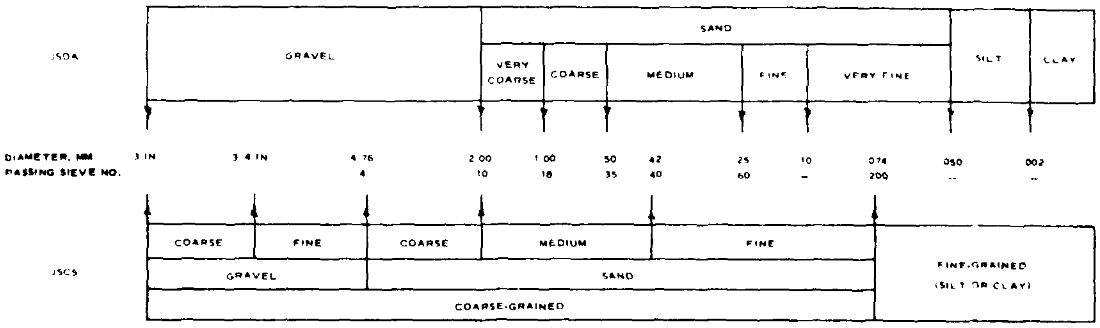
Sand: Sample consists of 85% or more sand; percentage of silt plus 1-1/2 times the percentage of clay shall not exceed 15%.
Loamy sand: Sample consists of at the upper limit 85 to 90% sand, and the percentage of silt plus 1-1/2 times the percentage of clay is not less than 15%; at the lower limit it consists of not less than 75 to 85% sand, and the percentage of silt plus twice the percentage of clay does not exceed 30%.
Sandy loam: Sample consists of either 20% or less clay, with the percentage of clay exceeding 30%, and 52% or more sand; or less than 7% clay, less than 50% silt, and between 43 and 52% sand.
Loam: Sample consists of 7 to 27% clay, 28 to 50% silt, and less than 52% sand.
Silt loam: Sample consists of either 50% or more silt and 12 to 27% clay, or 50 to 80% silt and less than 12% clay.
Sandy clay loam: Sample consists of 20 to 35% clay, less than 28% silt, and 45% or more sand.
Clay loam: Sample consists of 27 to 40% clay and 20 to 45% sand.
Silty clay loam: Sample consists of 27 to 40% clay and less than 20% sand.
Silt: Sample consists of 80% or more silt and less than 12% clay.
Sandy clay: Sample consists of 35% or more clay and 45% or more sand.
Silty clay: Sample consists of 40% or more clay and 40% or more silt.
Clay: Sample consists of 40% or more clay, less than 45% sand, and less than 40% silt.

b. Percentage of components in USDA soil classifications

Figure 2. USDA Soil Textural Classification and components



a. Predominant USCS soil types superimposed on USDA textural triangle



b. Comparison of USCS and USDA grain sizes

Figure 3. Comparison of USCS and USDA soil classification systems (from Meyer and Knight 1961)

sites located in 44 states. The USCS type was identified from Atterberg limits and mechanical analysis (generally sieve analysis) data. The USDA type generally was identified from textural information derived from a hydrometer analysis (Meyer and Knight 1961).

28. Soil strength. Soil strength is the principal factor affecting the trafficability of a soil. Strength values result from the combined effects of soil moisture, grain size, grain shape, mineralogical composition, organic content, plasticity, density, previous stress history, rate of loading, and drainage during loading. The shear strength of soil for trafficability is determined with a cone penetrometer. The effort required to force the instrument through the soil is indicated on a dial with numbers ranging from 0 to 300. Perhaps the two most important (and the most predictable) factors of soil strength are grain size and moisture content, although the latter may be highly variable.

29. Soil profile. A vertical section of the soil from the surface downward through all of its horizons into the parent material is known as a soil profile.

30. Moisture content. Moisture content in soil is the water occurring in the pore spaces. It is the ratio (expressed in percent) of the actual weight of water to the weight of dry soil, in a given sample. The percent pore space or porosity is a function of the size, shape, and distribution of the soil grains and their proximity to each other, i.e., density. A given soil sample would have less pore space, and hence less capacity for storing moisture, after it was compacted. Permeability is the characteristic that permits water to pass through the soil via interconnected pore spaces by percolation and capillary action.

31. Loam. Loam is a heterogeneous mixture of varying proportions of sand, silt, and clay. The predominant texture is denoted in a single or double designation such as sandy loam or sandy clay loam.

32. Sand. Sand is detrital granular material, usually quartz, ranging from 0.05 to 2.0 mm in the USDA classification system and 0.074 to 4.76 mm in the USCS.

33. Clay. Clay is a soil mineral particle having a diameter of

less than 0.002 mm in the USDA classification system and less than 0.074 mm in the USCS, in which it is grouped with silt.

34. Silt. Silt is a fine-grained soil intermediate between sand and clay in diameter. Grain sizes range from 0.002 to 0.05 mm in the USDA system and below 0.074 in the USCS, which does not distinguish it diameter-wise from clay particles. Silt particles may vary widely as to their mineralogical composition but commonly have large percentages of clay minerals.

35. Gravel. Gravel is an accumulation of rounded rock fragments, ranging in size from 4.76 to 76.0 mm in the USCS and 2.0 to 76.0 mm in the USDA system.

36. Grain-size distribution. The distribution of grain sizes in a soil is expressed in percentages of grain diameters, either in millimetres or inches, usually as a curve. (An example of a grain-size distribution curve is given in Figure 4.)

37. Density. Density is the weight of a soil per unit volume and is usually expressed as a dry unit weight. Densities vary with grain-size distributions in soil and many other factors.

38. Grain shape. Grain shape is expressed in degree of roundness or angularity. Grain shape influences soil density and also affects soil permeability and porosity.

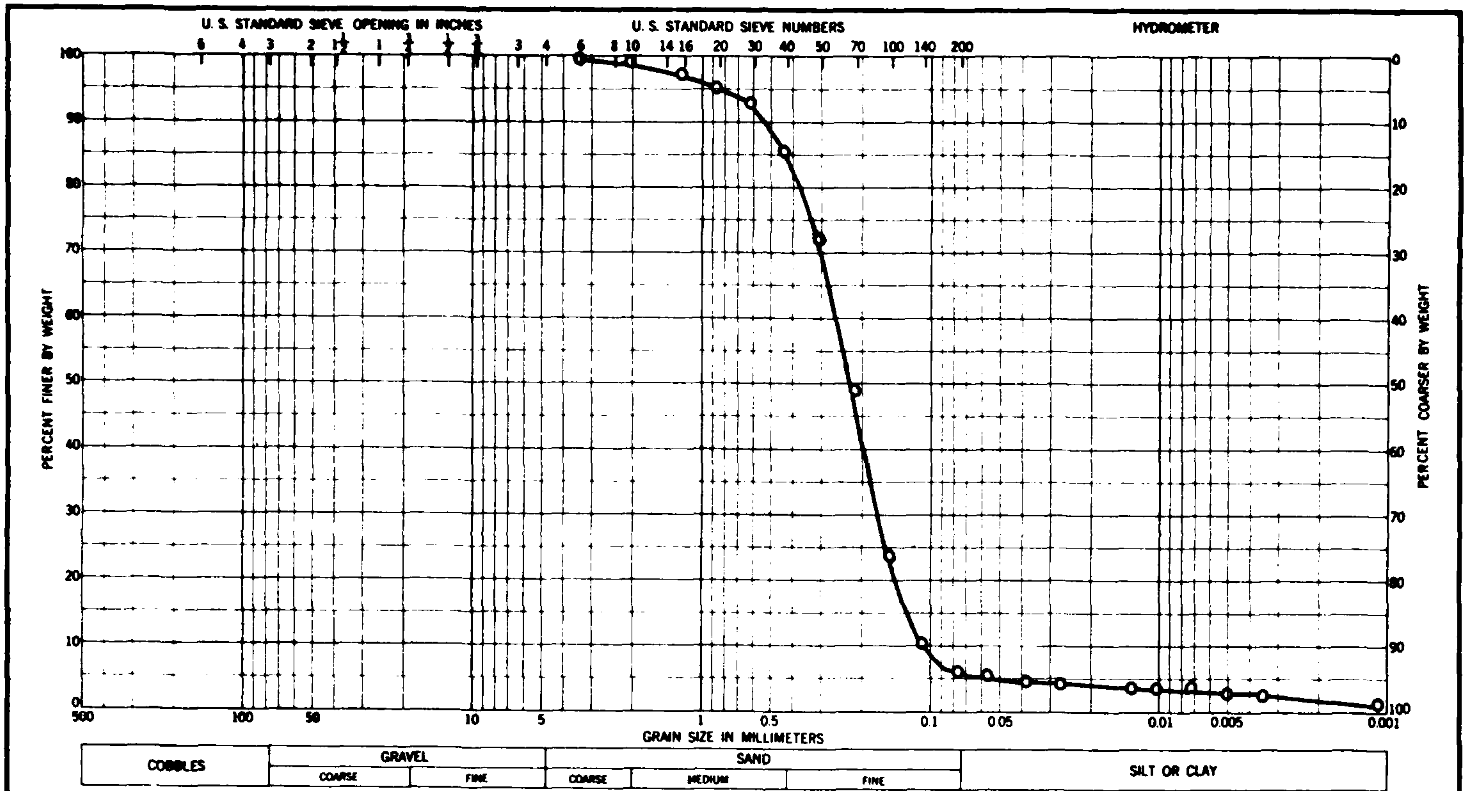
39. Depth to rock. Depth to rock refers to the depth of soil overlying rock. This may be a difficult determination to make since a transitional weathered zone usually occurs, making delineation difficult.

Terrain terms

40. Terrain factor. A terrain factor is an environmental factor describing an attribute of the landscape. Terrain factors include all attributes relating to soil, rock, surface water and drainage features, surface geometry or configuration, and vegetation.

41. Terrain type. A terrain type is a homogeneous area in nature characterized by specific class ranges of component terrain factors, i.e., surface geometry, surface composition, hydrologic geometry and surface water, and vegetation.

42. Terrain parameter. A particular kind of measurement of a



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
L3-23	C-6	SILTY SAND (SP-SM) TAN Gs = 2.66 GRID COORD 034125		NP		

Project TERRAIN QUANTIFICATION

Area GIFHORN, GERMANY

Boring No. 18

Date 23 NOV 79

GRADATION CURVES

Figure 4. Typical laboratory analysis

terrain factor is known as a terrain parameter. The parameter's terms and procedures of measurement are rigidly specified, and the parameter is designed for direct mathematical application to a particular technological problem.

Topography terms

43. Topographic position. Topographic position defines the relative position of a slope segment along a topographic feature extending from the lowest to the highest position. Intermediate positions are arbitrarily related to a model diagram, the relative positions identified either by number or by name. Typical designations might be bottomland slope or upper slope.

44. Dissection. Dissection is a measure of the density of drainage lines in an area. It may be expressed as total drainage line distance versus total area or number versus area. Dissection may be identified according to pattern, e.g., dendritic, which gives a vision of the areal arrangement of the streams. In mobility, all streams representing a deterrent to cross-country mobility must be considered. The actual characteristics of streams and their hydrologic characteristics are included under hydrology.

45. Slope. Slope is vertical rise per horizontal interval, usually expressed in percent. As a terrain parameter, slope is vehicle-related and could be defined as the smallest homogeneous interval that could be occupied by a vehicle at a given point in time. It should not be confused with obstacle slope, which is the bounding slope of obstacles in the path of the vehicle. Such slopes would include boulders and rows in agricultural fields. The distinction between macro- and microslopes can be stated in terms of relief generated in a given horizontal interval. Slopes as a terrain factor are characteristic of landforms occurring in the area of interest and would either be an averaging of component slopes or the most frequently occurring class.

46. Relief. Relief is a vertical differential of two points separated horizontally. It may be defined locally or on a regional basis. Locally, it may be the vertical distance between an interfluve crest and the immediately adjacent flow line, or in areas where drainage

patterns are poorly developed or lacking (as in desert areas) from high to adjacent low. To the most specific level, it may be the elevation differential of a simple slope segment. On a broader level, relief may be taken as the maximum difference in elevation in a specified area, such as a 1-km square, for example.

Hydrology terms

47. Drainage. Drainage patterns result when precipitation falls on elevated areas of soil and rock. Slope, relief, and rock or soil type determine the resulting drainage pattern and the amount of runoff occurring. Vegetation is an important factor to consider since it can substantially decrease the volume of drainage out of an area. The basic unit of drainage is the basin. Basins may be small or very large, i.e., thousands of square miles. The requirement is that all rainfall falling on an area will find its way to a main channel that drains the basin, except of course the water that percolates downward through the pervious surface soils. The main stream is fed by numerous tributaries that, in turn, are fed by even smaller tributaries and so on. A large drainage basin is then composed of numerous smaller basins. The pattern of streams within the basin is related to slope and relief and to the rock and/or soil type. The recognition of drainage patterns from maps or aerial imagery permits confident estimates of the materials on which they are superimposed.

48. Groundwater. All of the water falling on a drainage basin does not find its way to the main stream. A large percentage may be absorbed by the soils or percolate through the soil or rock into the groundwater table. This is known as recharge and the amount and rate depend upon the volume of water available and the permeability and porosity characteristics of the material. The level of the groundwater table is a function of recharge and structure of underlying rock, slope, and elevation, and of evapotranspiration.

49. Surface runoff. A relationship exists between the amount of rainfall that falls on an area and the amount ultimately carried beyond the area by stream channels (runoff). Runoff is controlled by many variables, such as rock and soil permeability and porosity, slope,

volume and density of drainageways, vegetation, soil moisture at the time of the rainfall, and relief-slope-elevation. Areas receiving runoff are usually low-level areas, densely vegetated, with porous soil.

Climate terms

50. Climate. Climate can be defined as the weather of a region in regard to characteristic ranges of precipitation and temperature, measured over extended periods of time (dependent largely on available records). Climate is highly variable; thus, boundaries between climatic types are ever-changing. The climates of the Federal Republic of Germany and the northeastern United States are classified as humid temperate with pronounced warm and cold seasons and with sufficient rainfall to sustain natural vegetation and agriculture.

51. Precipitation. The amount and distribution of rainfall is important in the development and change of terrain. Rainfall nurtures vegetation and promotes decay, weathers soil and rock and transports the eroded particles, replenishes the groundwater table, sculpts landforms, supports agriculture, and creates devastation by flooding.

52. Temperature. The history of all past rainfall and temperature has fashioned most of the landforms, both physical and cultural, now known today. Since most landforms are formed by either depositional or erosional processes or at least modified to some degree by these processes, temperature and rainfall are to a degree responsible for most of the terrain parameters of interest to vehicle mobility. Temperature and rainfall and, to a lesser degree, wind acting upon geologic materials in numerous relief and vegetation situations form the primary processes in the origin and change of terrain.

53. Wind. Wind may act as either an erosive or a depositional agent, sorting material and transporting it to different terrains. Wind carrying sand can have an abrasive effect upon soft rocks or indurated soils. Wind also creates waves which erode shorelines in one location and deposit the eroded materials in others.

Geology terms

54. Rock type. The term "type" applied to rock can have

different meanings depending upon the interest of the analyst. The geologist might type rocks as igneous, metamorphic, and sedimentary, relating them to their origin. The soil scientist might think in terms of grain size and cementation since this provides insight as to the nature of soils resulting when the rocks are weathered. There are many other examples, such as the chemical and crystal form, of interest to the mineralogist. However, grain size and crystal composition are the basic parameters of most interest to the mobility analyst since they determine the texture of the soil.

55. Structure. Structure in the sense used here refers principally to the attitude of the bedding or the dip of the formation. Structure is not a universal indicator of shape since horizontally bedded rock may weather into steeper slopes than dipping formations. For example, take the pepinos in northern Puerto Rico--conical hills which stand as erosional remnants of horizontally bedded limestone. Jointing is an additional aspect of structure to be considered, since it not only contributes to structure but also to the passage of groundwater.

56. Rock. Rock is a naturally formed consolidated or unconsolidated material (not including saprolite) composed of two or more minerals and having a degree of chemical and mineralogic constancy.

57. Saprolite. Saprolite is completely decomposed, often earthy, rock lying at the original site of its composition. If the rock from which the saprolite has decomposed is known, the term can be qualified as *basalt saprolite*, etc. The saprolite retains the original structure of the rock and thus is distinguishable from the overlying soil profile.

58. Mineral. A naturally occurring homogeneous, inorganic, crystalline substance is called a mineral.

59. Cryptocrystalline. Rocks composed of mineral crystals too small to be seen even with the aid of an ordinary microscope are called cryptocrystalline rocks.

60. Microcrystalline. Rocks composed of mineral crystals too small to be seen with the unaided eye but quite visible under an ordinary microscope are called microcrystalline rocks.

Study Areas

61. This study called for the selection of two geographically remote, but environmentally analogous, large areas. Additional criteria employed in the selection process and a brief discussion of the analogy between the two areas selected follow.

Criteria for selection

62. Military criterion. At the present time, many land areas in humid temperate climates of the world are militarily critical. A principal focus within this broad climatic zone is Western Europe, where North Atlantic Treaty Organization (NATO) nations are striving to maintain a state of military preparedness. Vital to the effectiveness of this defensive posture is current knowledge of the effectiveness of both NATO and Soviet ground systems in the terrains where action and counteraction may take place. While specific areas can be identified as the most probable battlegrounds from a terrain standpoint, the total of the entire zone of possible combat must be considered with equal emphasis. Since a broad spectrum of combative ground machines would be involved in such a confrontation, it is desirable that intelligence describing the terrain involved always be available in desired detail and terminology.

63. Practical criterion. Accessibility to the study area, freedom and ease of movement within the area, cooperation of indigenous authorities and personnel, cost, etc. were among the criteria employed in the selection process.

64. Availability of data. The ready availability of sufficient pertinent data was an important criterion.

Areas selected

65. The Federal Republic of Germany represents the most critical area, geographically, in Western Europe. It is believed that enemy encroachments would funnel through any of a number of militarily favorable routes, affording passage from contiguous satellite countries into the Federal Republic of Germany and from there into all of Western Europe. Clearly, the Federal Republic of Germany met the military

criterion. The Federal Republic of Germany also readily met the practical criterion and yielded more data than did other Western European countries.

66. After determining that the Federal Republic of Germany was a suitable area for the subject study, the next step was to select an analogous area in another part of the world where pertinent data were readily available. A formal, in-depth study was not made of the analogy of the Federal Republic of Germany to other areas, but a cursory examination indicated a good probability that the eastern United States, where a wealth of data was known to exist, was analogous. This choice was more or less confirmed during the course of the study when pertinent data from the two countries were examined in some detail.

67. The Federal Republic of Germany. The study areas in the Federal Republic of Germany are two distinctly dissimilar types--the central German highlands and the north German plains. The former occurs between the northern plain and the south German plain, an area of undulating to rolling plains and low plateaus. The central highlands are composed predominantly of low forested mountains and hills, a pattern broken only by occasional basins and alluvial valleys which traverse the area mainly in a north-south direction. The mountains are composed predominantly of folded sedimentaries intruded locally by Tertiary volcanics. The north German plain is a glaciated surface negotiated from south to north by several major river systems. The plains are undulating to rolling and are composed of a variety of glacial landforms, moraines and outwash being the most common. The plains are primarily in agriculture and are crossed locally by dense networks of canals. Where the soils are not suitable for farming, the land is devoted to coniferous forests.

68. United States. Physiographically, the study area falls into the Appalachian and Blue Ridge mountains and plateau provinces. The provinces are composed of low mountains and plateaus, foothills, and level to undulating plains between the belts of uplands. The slopes range from moderate to steep in the uplands, where numerous areas of bare rock occur, and gentle to moderate in the plains. The uplands are

primarily forested while the lower slopes and plains are largely in agriculture and pasture. Included in this area are large portions of Pennsylvania, Virginia, West Virginia, Maryland, New Jersey, Tennessee, Kentucky, New York, and North Carolina.

Analogy between the Federal Republic of Germany and the United States

69. For the most part, the Federal Republic of Germany falls into the humid temperate climatic zone of Western Europe. Variations in precipitation and temperature do occur in the Federal Republic of Germany both from north to south and from east to west. However, for the purposes of this study, the climate can be considered as a single type since subtle variations cannot be presently accounted for in the evolution of terrain characteristics, nor can paleoclimates extending back into time for millions of years be accurately evaluated insofar as their contributions to modern landscapes.

70. In the areas of the United States considered to be generally climatically analogous to the Federal Republic of Germany, smaller areas were identified where geological conditions are also analogous to the Federal Republic of Germany. The most important geologic factors of relevance to this study are structure and lithology. Structure controls topography to a large extent and thus controls the development of landforms. Lithology describes the composition and layering of the geologic material of which the landforms are composed. The lithology is altered by the long-duration influences of climate and also is responsible for the compositional and morphological character of the landform.

71. Within these smaller areas of uniform geologic conditions, areas were further identified where variations in slope occurred. A sufficient number of sites were selected to ensure that the complete range of parameter variations had been identified. All of the areas in the United States were characterized by information gained from a search of available literature which fortunately provided soil and topographical data in desired detail. Unfortunately, the geological data were generalized.

72. To obtain an initial assessment of the validity of applying

the analog concept to soil texture, numerous sites were visited in the Federal Republic of Germany to collect ground truth data. These data were in areas climatically and geologically similar to the sites in the United States. In addition, topographic variations similar to those of the United States sites were included. Comparison of data from both areas confirmed an acceptable degree of analogy between soil texture in the United States and the Federal Republic of Germany, provided the primary genetic factors are similar and those secondary genetic factors meaningful to the development of those parameters are also similar.

Data Sources

Climate

73. Fortunately, climatic data are plentiful for both the United States and the Federal Republic of Germany. These data are both in the form of climatic maps and statistical data recorded hourly (or at even closer intervals) on temperature, rainfall and snowfall, and wind direction and speed. These data are generally available, although for specific stations in the Federal Republic of Germany, present channels of acquisition are proving time-consuming.

Topography

74. The determination of topographic factors can be adequately and consistently made from 1:50,000 topographic maps with comparable contour intervals. These are available for all of the Federal Republic of Germany and most of Western Europe. Far greater difficulty is encountered in extracting data regarding geologic structure and lithology from available sources.

Geology

75. Geologic maps are available for the Federal Republic of Germany at many scales and vary widely in content. Large-scale maps (1:25,000) are available for large portions of the Federal Republic of Germany but may vary in technical content from one area to another. The remainder of the Federal Republic of Germany is covered by smaller scales ranging up to 1:1,000,000. Considerable diversity occurs in the

content of geologic maps, however, whether it be in the Federal Republic of Germany or the United States. This variation in content is not necessarily related to scale. In addition to the considerable variation in technical content there may be appreciable generalization in some maps. For instance, in a 1:250,000 map, sandstone, limestone, and shale may be grouped under the term "sedimentary," even though the physical and chemical characteristics of the three rock types are significantly different.

Alternate topographic and geologic data

76. Maps do not represent the sole source of geologic and topographic data. Remote sensing data, soil and rock borings, personal communications, ground reconnaissance, and documentary data should be and were to varying extents relied upon to provide additional input to the final product. The degree to which these data can be incorporated is dependent upon several variables:

- a. Economic. The cost of acquiring all data relevant to ensuring optimum determination of relevant soil parameters would be considerable. It is assumed, however, that if the need becomes urgent cost would be no object.
- b. Time. The time required to acquire all available relevant data and to reduce, analyze, and incorporate these data into factor maps covering large study areas would be enormous. This would suggest some selectivity in data acquisition and generalization in its utilization.
- c. Security. Certain source data are classified and require priority for their acquisition. The use of sensitive data requires special handling and storage. Reports and maps using classified data must themselves be classified. Still, if the need is urgent, such problems can be resolved.

Field Trips to the Federal Republic of Germany, 1978 and 1979

77. During the summers of 1978 and 1979, U. S. Army Engineer Waterways Experiment Station (WES) personnel conducted field trips to the Federal Republic of Germany. The 1978 field trip was intended to

collect terrain data to update the data base of the Army Mobility Model to determine terrain effects on vehicle mobility and countermobility. The principal focus of this trip was on the collection of vegetation data, although soils data were taken at many of the sites. In addition, hydrologic, surface roughness, and road data were taken. During the 1978 field trip, terrain data were taken at two study areas (Figure 5): Fulda area, in the east central German highlands; and Wolfsburg, in the northeast German plains. A smaller study area consisting of three 1:50,000 quadrangles was selected during the 1978 field program southeast of Frankfurt including the cities of Aschaffenburg and Alzenau. Here the occurrence of igneous and metamorphic rocks provided an opportunity to examine rock-soil relationships not encountered in the principal study areas or even in close proximity to those areas. The time spent in these areas was considered necessary since the rock types (granite, gneiss, and schist) were common in the Federal Republic of Germany and in analogous U. S. areas. Outcrops were examined and detailed rock descriptions together with genetic factor data were recorded. Representative soil profiles were logged and samples taken for laboratory analysis.

78. The purpose of the 1979 field trip was to collect terrain data to be used in formulating a translation routine for developing a mobility-terrain data base. Four study areas were selected for data collection during this trip (Figure 5): (a) Trier, in the west central highlands including the valley of the Mosel; (b) Heilsbronn, in the central part of the South German Plains; (c) Giessen, in the Central German Highlands, lying immediately west of the Fulda area; and (d) Braunschweig, in the North German Plains, lying immediately west of the Wolfsburg area. All types of terrain data were collected at these four areas including vegetation, soils, hydrologic, surface roughness and obstacles, and road data--e.g., width, width of shoulders, profiles of flanking ditches, radius of curvature, angles of intersection, and surface.

79. No effort was made in this report to discuss any part of these two data collection programs not related to texture or the variables controlling it. The results and analysis of these data are

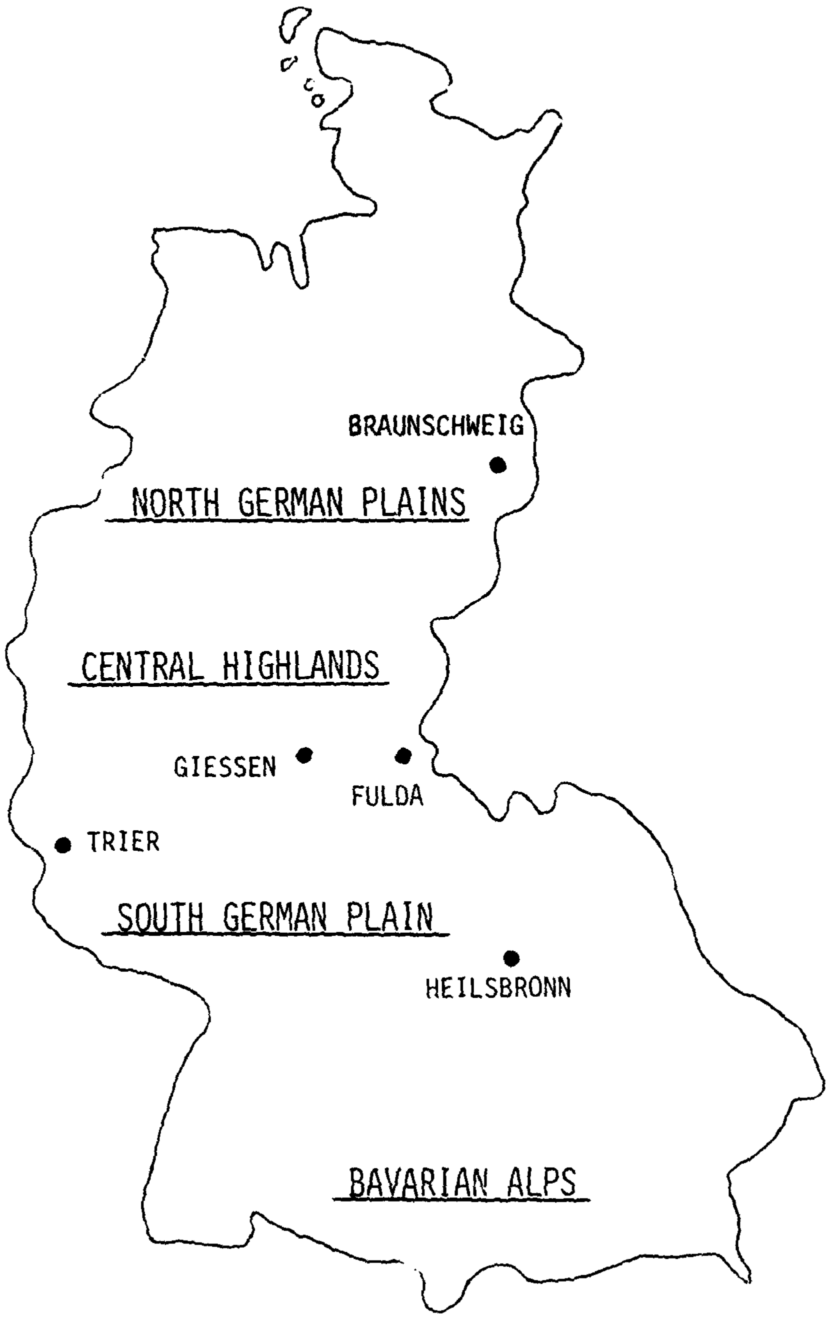


Figure 5. Federal Republic of Germany 1978, 1979 field data collection areas

scheduled to be included in future reports (probably during FY 82). The sample sites in the Federal Republic of Germany were on both occasions preselected by personnel of the Mobility Systems Division, Geotechnical Laboratory, WES. The principal criteria for site selection were to sample all major terrain types occurring within the study areas and to establish the range of variation of the terrain factor parameters within the major terrain types. Some special consideration was given to questionable or unique terrain features appearing on the topographic maps or the aerial photography to determine their significance to mobility. Many of the sites were multiparameter sites; for instance, a single site area, which was often a 1-km square, might be selected to include the collection of vegetation, hydrologic, surface roughness, soil, and road data. These multiparameter sites resulted in a significant savings of time normally expended in traveling from site to site.

Site selection criteria

80. The sites selected for this study were based on criteria similar to that of the mobility sites. The principal purpose of the sampling was to establish relationships between soils and various parent materials in the Federal Republic of Germany and statistically compare these relationships with soil-parent material relationships developed for analogous areas in the United States. Since the objectives of data collection for this study were subordinate to the overall field program, this investigator (the author) was not involved in the selection of the study areas in either year. The result was that the field programs were conducted in study areas of relatively low priority to this investigation. The sites selected within the study areas (hereinafter referred to as geology-soil site) were those which offered the most promise of providing comparative parent material-soil data. Diversity of parent material was the principal selection criterion with sufficient sites selected in each geologic unit to establish the range of variability of the associated soils. The sites were selected on 1:50,000 topographic maps of the Federal Republic of Germany prepared by the Defense Mapping Agency Hydrographic and Topographic Center (DMAH&TC) and 1:250,000

Military Engineering Geology (MEG) maps prepared by USAREUR. The geology map lithologic boundaries were transferred from the MEG maps to the topographic base. Sample sites were selected in each geologic unit with sufficient sites to determine lithologic variations within each unit. The lithologic descriptions of the rock units on the MEG maps were considered adequate for site selection; however, the areal distributions of the rock units proved on numerous occasions to be inaccurate. Since the geologic data sources for the compilation of the MEG maps were not recorded on the maps, it was impossible to determine how the boundaries between the geologic units were determined. Additional consideration was given to variations in slope, relief, and topographic position to relate the variability of the soils to these factors. Far more sites were selected than could have been visited within the time frames of the two field programs. However, the sites were assigned priorities, with the highest priority given to those lying in close proximity to mobility sites. It should be pointed out that high priority was given to these sites only to accommodate the mobility data collection schedule. Many of the sites relegated to low-priority positions in the sampling hierarchy actually had high informational potential. Soils data were taken at all mobility sites for field classification; in many cases bulk samples were taken for laboratory analysis. In all cases soils were classified using USCS standard field classification procedures. The field classifications were compatible with laboratory classifications in most instances, although field assessments of particle size percentages and plasticity characteristics resulted in many borderline decisions as to soil type. For example, the distinction between an SC and a CL soil or SM and ML could not in some cases be conclusively determined in the field.

Site investigation procedure

81. A general, but necessarily flexible, procedure was followed during each geology-soil site investigation. This procedure is summarized in the following steps. A modified version of this procedure was followed at the mobility sites.

82. The sites were located as accurately as possible on the

1:50,000 quadrangles. Location was facilitated by the fact that the site was selected as representative of the surrounding area and precise location was not important. Generally the maps were adequate for navigation purposes.

83. The area of the site was inspected to determine whether the soil-geology conditions were in conformance with the description developed from the topographic and geology maps. At residual soil sites, initial effort was directed at identifying the parent material. Rock outcrops were sought and were considered as conclusive evidence. If outcrops were absent, boulders and rock fragments were accepted as alternative evidence. Care was taken to determine if the rock specimens were consistent in their characteristics and, if not, to determine whether different rock types occurred within the area. Interbedded sedimentary rocks were not uncommon. If no rock specimens were observed on the surface, an attempt was made to determine their possible presence beneath the surface with a 4-ft soil sampler (Oakfield Punch). Rock specimens, whether surface or subsurface, were examined carefully and the following characteristics were recorded:

- a. Mineralogical composition: primary, secondary, and even trace minerals were noted if present. In granite, the primary mineral is feldspar (potassium), quartz is secondary, and biotite is common with or without minor amounts of hornblende and augite.
- b. If the rock was sedimentary (also some metamorphics), the cementing material was determined. The most common types are calcium carbonate, silica, iron oxide, and clay.
- c. The grain size was estimated. If variability was evident, then the range was determined. In sedimentary rocks the texture is normally identified in the designation, i.e., sandstone, siltstone, clay shale, etc. In sandstone the texture may range from fine- to coarse-grained but usually a single texture predominates. Small rock samples considered typical of the site were taken for more leisurely office examination or possible petrographic analysis. Modifying terms were used when appropriate for more specific descriptions, e.g., silty shale, mica schist, hornblende schist, and quartz diorite. Figure 6 is a typical site description.
- d. Color was noted. Red rock is a good indication of iron

Site No. 5, Friday, 11 August 1978

Location: Lauterbach, Federal Republic of Germany, Series L5322, 1:50,000, 443x078, upper hill slope in mixed forest, slope greater than 20 percent

Soil profile in inches

+1-0	Dark brown, moist, decayed organic matter
0-1	Dark gray, silty, clayey, fine-grained sand with organic matter (SM)
1-3	Gray-brown, fine-grained, silty sand (SM)
3-15	Red-brown, clayey, silty sand with sandstone fragments (SM)
15-20	Red, silty, clayey, fine-grained sand with quartz fragments and pebbles (SM)
20-34	Red, clayey, fine-grained sand with sandstone fragments (SC) or sandy clay (CL)

Rock description: No rock outcrops at site; however, sufficient fragments of sandstone were present to establish sandstone as parent material. Sandstone mapped on MEG maps.

Sandstone: Fine- to medium-grained, friable, subangular, weathered, red, cemented with silica, and stained with iron oxide. Quartzitic sandstone.

Soil and rock samples taken.

Photography: Roll 4, Exposures 1 and 2

Figure 6. Typical site description

compounds such as iron oxide cement in sandstone or iron-bearing igneous rocks where the iron has oxidized, appearing on the grains and in voids between the grains. Color is also useful in the identification of rocks; e.g., basic rocks are usually dark, while acid rocks are white or light shades. In the optical differentiation of feldspars, potassium feldspars are lighter in color than basic feldspars (Na, Ca).

e. Numerous physical tests may be useful in the field identification of rocks, e.g., hardness, cleavage, fracture, luster, streak, specific gravity, crystal structure, tenacity, taste, and acid test (for carbonates). A good book on the field classification of rocks and minerals is an essential item for field use. If the identification of the rock should prove difficult, a representative sample is collected for laboratory analysis. If rock specimens are observed, representative soil profiles are taken at different topographic positions along the slope of the geologic feature to determine thickness, changes in texture, soil moisture if practicable, and the incidence of rock fragments larger than gravel. If no rock is observed, a representative soil sample is taken for further study. It is possible that the rock is deeply weathered and residual soils attain depths of greater than 4 ft, even on upper slopes or where thick deposits of loess may blanket the slopes.

84. If time permitted, alternate sites were selected some distance from the initial site to determine whether there was any variation in the rock type. Often there were lateral or vertical facies changes in rocks in relatively short intervals, which could influence the textural character of the soil.

85. Genetic factors of relevance to soil texture and soil moisture were identified and evaluated at each site. Rock-related factors in addition to lithology include bedding thickness, fracture and joint patterns and occurrence, distribution, dip and strike, and density and size of boulders. Topographically related factors include slope, relief, elevation, and topographic position. Climatic factors of relevance include rainfall and temperature, but the latter could not be determined in the field and had to await office examination of climatic data. These current climatic data are of little relevance to soil type since soil formation has taken place over an extended period of geologic time during which numerous climatic changes have taken place, but climatic

data are of some importance in areas where no ground data are taken.

86. Extensive reconnaissance was performed within the study areas principally to determine the homogeneity of vegetation patterns appearing on the aerial photography or orthophoto maps. This permitted an assessment of the range of variability of the structural components of the vegetation pattern. Since this reconnaissance was most often conducted in upland forested areas, it afforded an excellent opportunity to note rock outcrops and areas with a high incidence of rock fragments strewn over the surface. Such sites were located as accurately as possible on the topographic map and specimens collected for field and office identification. Following identification, the geologic map including the site was checked for agreement. If not in agreement, an effort was made to determine the areal extent of the inconsistency. This was possible only by additional reconnaissance if time permitted. At all reconnaissance sites representative soil profiles were recorded and genetic factors determined. When vegetation sites were selected to determine pattern variability, the general area was searched for rock outcrops or loose specimens. Always the geologic map was checked at sites where in situ rock specimens occurred and representative soil profiles were examined and classified to ascertain conformance with the map.

87. Quarries afforded an excellent opportunity to examine large exposures of rock. In addition to identification and classification, bedding characteristics, fracture patterns, depth of overburden, lithologic consistency, and depth of weathering were determined.

88. At sites where field identification of rock and residual soils was not possible or was questionable, representative samples were collected for laboratory examination. Soil samples were taken from both the 0- to 6-in. and 6- to 12-in. layers and occasionally at greater depths, when identification was considered relevant.

Comparison of map and field data

89. Soil profiles taken at geology-soil sites and mobility sites where soil-rock associations occurred were classified in terms of the USCS for the 0- to 6-in. and 6- to 12-in. layers. These profiles were tabulated for each rock type in identical fashion to the tabulations

prepared for rock types in analogous portions of the United States. Since the data were restricted to relatively homogeneous stratigraphic units within the study areas, the 1:250,000 MEG maps covering all of the Federal Republic of Germany were examined in an effort to give rock types a broader lithologic base. The site data and the map-derived data were examined separately. Only three common rock types, i.e., sandstone, basalt, and limestone, had been sampled sufficiently to permit any meaningful analysis and as previously stated these samples came from the same stratigraphic units. The comparison was predictable. Of a total of 72 sandstone field sites in the Federal Republic of Germany where rock-soil data were taken, the 0- to 6-in. layer was classified as GM 1 percent of the time, SM 72 percent, SP 8 percent, SC 7 percent, ML 4 percent, CL 6 percent, and CH 3 percent. Of 74 map units taken from the MEG maps covering all of the Federal Republic of Germany the surface layer of residual soils derived from sandstone was identified as SC 43 percent, SM 36 percent, CL 15 percent, and ML 5 percent. Note that there are more soil types in the field data (7) than there are in the map data (4) and that there is a high concentration of one soil type (SM, 72 percent) in the field data, while the map data are more widely distributed. The results here reflect generalizations during the preparation of the maps and a greater diversity in the stratigraphic units. Thus, data are restricted to a small area on the one hand (field data) and data are generalized on the other (map data). Still, they are in close agreement, with 90 percent of the site samples classified as sand as opposed to 79 percent of the map unit data. The distribution of USCS soil types derived from sandstones in the United States gives evidence of a much wider range of lithologic diversity. This is understandable since each profile was taken at different geographic locations covering most of the northeastern United States. This diversity is reflected in the sandstone data shown later in the text. The gravel fraction suggests the common occurrence of conglomeritic sandstone as the parent material or fragments of sandstone are not yet reduced to individual grains by weathering. Silt particles are a subordinate yet significant component of some sandstones, while the clay fraction may result from clay and iron oxide cementing materials or in some sandstones the reduction of feldspar grains to clay minerals. Statistical data were not presented for the Federal Republic of Germany rock-soil relationships mainly because, with the exception of sandstone and possibly basalt, too few profiles were taken of other residual soil types. The soils data taken from the 1:250,000 MEG maps are obviously generalized and compilations based on these data would not realistically reflect the diversity of soil types resulting from lithologic variations in the parent rock. Although only limited data were acquired for other rock types during the field programs, the associated residual soils were in general agreement with the soils data from analogous U. S. cities.

Sites in the northern Federal Republic of Germany

90. Numerous soil profiles were obtained in the glaciated northern plain of the Federal Republic of Germany. Unfortunately, it was not always possible to relate the soil sites to specific glacial landforms as was possible with the U. S. soil data. The 1:250,000 MEG maps delineated major glaciated areas but failed to identify individual glacial landforms. No aerial photography of the area was available, but photography during future studies in the area or in analogous areas would be useful in landform analysis. Loessial soils deposited by silt-laden winds from the north during the glacial epochs were sampled in the Central German Highlands. They were found to be similar to deposits occurring in the central United States. The soils were predominantly unstratified, calcareous silts with varying percentages of sand or clay. The soils were predominantly ML with some SM and CL occurring as textures varied from one area to another.

Laboratory analysis

91. Laboratory tests were performed on all mobility site soil samples for the 0- to 6-in. and the 6- to 12-in. layers. These tests were grain size distribution for particles held on the No. 200 sieve and hydrometer tests for particles (silt and clay) passing the No. 200 sieve. Liquid and plastic limits were determined for the fine fraction when

appropriate. Specific gravities were determined and the samples classified in USCS terms. A typical analysis is shown in Figure 4. In addition, soil moisture and density values were determined for the 0- to 6-in. and 6- to 12-in. layers.

92. Because of economic constraints, rock-soil samples collected during both the 1978 and 1979 field programs were not analyzed in the laboratory. However, there was sufficient overlap in the mobility and rock-soil sites that the overall analysis and evaluation of the rock-soil site data would not be significantly inhibited. This was due principally to the fact that there was not much lithologic diversity in the various study areas and that the field identifications were in most instances considered reliable. Rock specimens that could not be confidently identified in the field were bagged and shipped to the office where more precise identifications were performed.

PART II: GENETIC ENVIRONMENTAL FACTORS INFLUENCING SOIL DEVELOPMENT

General

93. Physical and climatic factors responsible for the development of natural terrains of the world are both numerous and diverse. Cultural factors contribute to this development and often override the natural phenomena. The influence of certain of these factors in the development of landforms that significantly affect various military activities, viz., vehicle mobility, can be direct or apparent in some cases while indirect or subtle in others. Slope, relief, and the structural aspects of vegetation are factors directly affecting ground mobility, while temperature and rainfall are factors whose effects are more subtly applicable.

94. A necessary step in the development of a methodology for the prediction of values of terrain parameters is to first identify the physical and cultural factors controlling the parameter values. Soil type or texture, the parameter emphasized in the study, is specifically the product of the type of geology, climate, topography (slope and elevation), biological activity, time, and physical and chemical processes acting upon the parent material (Figure 7).

95. Some terrain factors may serve as indicators of parametric values while not relating directly to them. For instance, certain plant species may occur only in relationship with moist or saturated soil. Others may give an indication as to the depth of the groundwater table. Still others may be found only in sandy soil; others only in clay, and still others in saline soils. Drainage patterns often identify the soil and rock types in which they develop.

96. Thus, each terrain parameter is directly relatable to a unique set of genetic factors which has been responsible for its evolution. In addition, each parameter is indirectly relatable to other genetic factors which, although of lesser importance, must still be considered. If these primary and secondary genetic factors can be

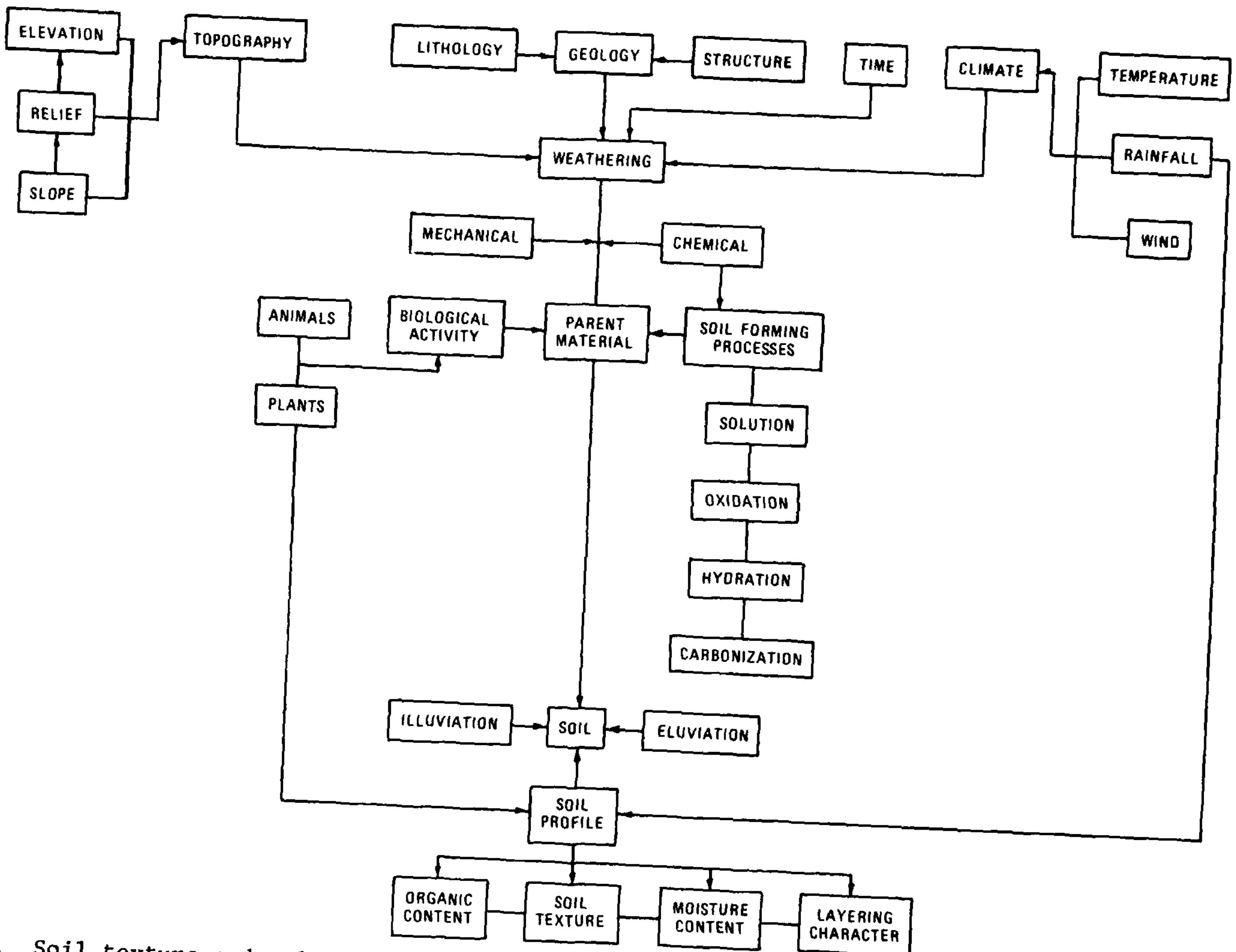


Figure 7. Soil texture and related parameters resulting from the combined effects of primary genetic factors and natural and chemical processes on parent material

accurately determined from available source material and the natural process integrating these controlling factors is known, then confident determination of parametric values becomes possible.

Genetic Factors

97. The primary genetic factors are climate, time, geology, topography, and biological activity, of which climate and biological activity are considered active and the remaining factors passive. These are discussed in the following paragraphs.

Climate

98. The role of climate in the evolution of world landforms has never been adequately ascertained. Examination of the major climatic regions of the world in terms of their constituent landforms convinces the analyst that climate beyond any doubt plays a major role in geomorphological development. Tropical and desert regions, for example, exhibit notably dissimilar families of landforms. The abundance of moisture and the inconsequential range of daily as well as seasonal temperatures in the former have resulted in relatively luxurious plant growth, deep soil horizons, and rounded slopes, while in the latter the absence of moisture during all seasons has permitted only sparse vegetal growth, thin soil development in areas of exposed rock, and higher slope angles. Even certain rock types may display opposing characteristics; limestones in arid regions are perhaps the most resistant of all rocks, while in the tropics, because of vulnerability to solution, limestones are among the least resistant to weathering.

99. Classification. In order to compare diverse areas of the world climatically it was first necessary to select a climatic classification. Examination of available climatic literature revealed no significant innovations in classification since the introduction of the Köppen climatic classification system in 1918 (Strahler 1967). This system is essentially quantitative in that climatic types are based on the analysis of data taken at numerous weather stations positioned around the world over a period of years. Boundaries were established,

departmenting the world into five major climatic types, each with discrete and rigorous temperature and precipitation values gratifyingly harmonious with gross vegetational and pedologic boundaries. It should be kept in mind, however, that the boundaries may often have been established on the basis of vegetational or pedologic change, particularly in areas where meteorological data were scant or lacking. Also climate, being an ever-changing and cyclic phenomenon, is perpetually establishing new boundaries. An obvious advantage of the Köppen system is the symbolic method of designating climatic types. This "shorthand" obviates the otherwise awkward and cumbersome descriptors which would otherwise clutter the maps.

100. Climate, as considered in this study, is based entirely upon the Köppen classification and is expressed in ranges of temperature and precipitation and the seasonal ranges and distributions of these factors.

101. The Federal Republic of Germany and the United States. The Federal Republic of Germany and climatically analogous portions of the United States are located within a humid temperate or humid mesothermal climate. The Köppen-Geiger notation for this climatic zone is Cfa, where "C" means "warm temperate climate," "f" means "sufficient precipitation in all months," and "a" means "warmest month, mean over 71.6°F (22°C)" (Strahler 1967). For convenience in this report, this climate will be referred to as "humid temperate climate."

102. This climate has seasons that are designated as summer and winter. Plant growth is dormant during periods of low temperature. The zone is characterized by a large range in annual temperatures. Normally, summers are mild, although hot periods (temperatures greater than 23°C) are not uncommon. Winters are cool or even cold but temperatures are generally higher than 0°C. Mean annual temperatures average about 10°C for all of the Federal Republic of Germany, ranging from 8°C in the northern plains to about 12°C in the central highlands. For the zone the mean temperature of the coldest month is 18°C down to -3°C. There is sufficient precipitation for plant growth during all months of the year. For the zone, including the analogous portions of the United

States, precipitation ranges from 20 to 60 in. For the Federal Republic of Germany, rainfall occurs during all the months of the year but mostly during the summer. The amounts are greatest in the highlands, averaging about 34 in. In low-lying protected portions of the country, rainfall may be 20 in. or less. Yearly amounts and distributions may vary significantly. It should be borne in mind that there is only general albeit adequate correspondence climatically between the Federal Republic of Germany and analogous portions of the United States. Variations do occur locally not only between the two countries but also within the countries themselves. In addition, there have been significant climatic changes in the two areas during the period of soil development, i.e., approximately 1,000,000 years before the present. Even if all of these climatic changes were known, they cannot be quantitatively evaluated as to their singular contribution to the development of modern soils.

103. Climatic effects on soil formation. Soils form from rocks at a much faster rate in humid climates than they do in arid and subarctic climates.

104. Rainfall occurring within an area (for example, a hill or a mountain) is disposed of in two ways: (a) runoff, and (b) downward percolation to the groundwater table. In the first case water that is not absorbed by the soil moves downslope until it reaches a drainageway providing external drainage. It may do so in established drainage patterns, e.g., dendritic, which are characteristics of the rock and soil into which the channels are cut. From map analysis and interpretation of aerial photography, drainage patterns can provide valuable clues to the identity of the parent materials of the topographic features on which they occur. Rainfall may also move downslope by sheet flow where a thin, essentially continuous film of water moves downslope over rock and soil and is not concentrated. In the case of drainage channels, eroded rock debris and soil are transported downslope to be deposited at a lower level. Materials deposited at the base of a topographic high are called alluvial fans and where they coalesce, alluvial aprons. Some finer material is transported to major drainageways and subsequently is

removed from the area to be deposited in floodplains and deltas. Sheet flow moves unconsolidated, relatively fine-grained material varying distances downslope, depending upon the grade, and usually deposits the transported material upon existing deposits, thus forming a thin veneer of alluvial material upon residual soils. In some topographic situations the flow stagnates because of loss of grade and water stands for short intervals of time until it can be absorbed by the underlying soil. The water percolating downward through the soil eventually reaches the water table and contributes to raising its level. The proximity of the water table to the surface is variable and dependent upon many factors, which shall not be discussed here.

Time

105. Much has been written regarding soil as an indicator of geologic time. A more difficult and seldom addressed problem is the prediction of soil characteristics if geologic time is known. Of the five recognized soil-forming factors, two (i.e., climate and biological activity) are active and the remaining three (i.e., parent material, topography and geology, and time) are considered passive.

106. A distinction should be made between soil as defined by the geologist and soil as defined by the soil scientist. To the geologist, all unconsolidated mineral material is considered soil. To the soil scientist, soil is parent material which has undergone both chemical and physical (and to a lesser degree biological) change and can be described in terms of vertical zonations, each of which has distinct chemical and mechanical characteristics. For this study, only the texture and engineering behavior of the soil are considered relevant.

107. For this reason, time should be considered in a different context. To the mobility analyst only the time required to reduce the soil to its present textural character is considered relevant. The more subtle chemical and layering changes which take place over hundreds and even thousands of years are only important when they result in physical changes affecting the textural profile of the soil.

108. Since the soils examined in this study are essentially residual, consideration must be given to the time required for the

parent material of these soils (i.e., rock) to weather into soils. Sandstone, for example, breaks down mechanically at a faster rate than limestone; however, the reverse is true in regard to chemical weathering in humid temperate climates. The residue created by the weathering of sandstone undergoes little chemical change and the formation of a unit depth of soil from sandstone proceeds at a much faster rate than from limestone, which weathers rapidly chemically but the residue is largely removed by solution.

109. Little is known concerning the time required to develop a given thickness of soil since other soil-forming factors must be considered. On resistant rock even a thin veneer of engineering soil may take hundreds or even thousands of years to develop. It would seem a safe assumption that the depth of soil developed from a given rock type would increase with age provided the other soil-forming factors are constant. The fact that they do not remain constant is responsible for the often baffling deviations from office-predicted values which occur in nature. Soil development does not necessarily proceed at a uniform pace over periods of geologic time. A mature profile may develop over a relatively long period of time and appear morphologically and texturally similar to a profile that has developed over a relatively short period of time under conditions of intense weathering and leaching.

110. Geologically old rocks may have only recently outcropped as a result of tectonic activity or erosion. Thus, soil developed over this rock may be thin and immature, while soil over geologically younger rocks which have been exposed at the surface for a longer period of time is relatively thick and mature. This circumstance can be compounded by the types of rocks involved. For instance, quartzite in the former case and marl in the latter would accentuate the weathering disparity.

111. The age of a soil from a certain parent material is not necessarily consonant with the age of the landscape upon which it is developing. During the evolution of a landscape new environmental conditions may occur that will alter the development of the soil. When

a soil reaches maturity, it is in equilibrium with the processes and factors acting upon it.

112. In the northern Federal Republic of Germany and the northern United States, soils that were developed prior to the glacial stages during the Pleistocene epoch were eroded by the advancing ice sheets and redeposited in southern areas as moraines or outwash. Only soils in upland areas and south of the glaciated areas were preserved. In the Federal Republic of Germany, these were the residual soils sampled during the 1978 and 1979 field activities.

Geology

113. Geological factors influencing soil development are structure and lithology, which provide parent material, determine topography, and affect the rate of erosion. These are interrelated since lithology may influence structure. Structure and lithology together with climate are the major controls for the development of topography or landforms. Structure pertains principally to the attitude, disposition and arrangement of the bedding in sedimentary rocks or to the morphology of igneous intrusions. Lithology identifies the composition of rocks of igneous, metamorphic, or sedimentary origin. The composition of rocks includes both their physical and chemical characteristics. In this context, lithology identifies the parent material of residual soils.

114. Rocks of different geologic structure and lithology will weather into different landforms and associated soils. These landforms and soils are generally predictable, provided adequate sources of information are available. The most desirable sources of information are geologic and topographic maps and aerial imagery, the scales of which are related to the desired level of detail.

Topography

115. Relief-elevation (gross topography). Gross topography enables a general distinction to be made between rugged hilly and mountainous areas and areas of low relief. While areas may be similar in regard to geology, process, and climate, differences in relief-elevation will result in significant differences in soil type and distribution, vegetation, and drainage. Gross topography should be used

only to establish general relationships, a means of compartmenting terrain into topographically high, intermediate, and low areas. This can be done with maps and imagery of almost any scale and contour interval.

116. Local topography. Local topography interacts with other primary and secondary genetic factors to exert numerous critical controls on soil development and characteristics. Slope, for instance, influences soil texture, thickness, and moisture content. Slope and topographic position help to identify areas on a topographic feature where erosional, depositional, or residual soil-forming processes are active or have been active in recent geologic history. Elevation is important in some instances, such as situations where summit portions of some topographic highs may be under the influence of different climatic conditions such as a higher incidence of cloud cover. The orientation of hills and mountains with respect to north affects the degree of solar insolation received throughout the year. Slope and elevation are important considerations in the determination of the groundwater table and thus influence soil moisture conditions.

117. Soils on relatively high topographic positions tend to be coarser than soils in topographically low areas since the erosive actions of water and wind tend to remove fine fractions of the soil from the high areas and deposit them in the low areas. In addition, there is a gravitational tendency for the coarser particles, especially stones and boulders, to migrate downslope until level ground is found which may or may not be at the bottom of the slope of the topographic feature. The soils on topographic highs are generally more loose, coarse, and friable than those at lower topographic positions. They also tend to contain less clay and humus than low-lying soils. Soils on high topographic positions generally hold moisture for shorter periods of time because of the greater opportunity for external and internal drainage. Soils in the lower topographic positions tend to be darker in color as a result of higher organic and moisture content than the soils on higher topographic positions.

118. Thus, an originally homogeneous soil tends to become impoverished of fines on the topographic highs and enriched on the

topographic lows. Wind-deposited soils are invariably uniformly graded silt or fine to medium sand. On the other hand, water- or ice-deposited materials produce soil textures ranging from clay to boulders, depending on the velocity of water at the point of deposition.

Biological activity

119. In humid temperate climates, biological activity may have a significant effect upon soil development and the characteristics of the soil, particularly in the upper horizons. Since the upper horizons, identified in USDA terms as the A and B horizons, correlate approximately with the 0- to 6-in. and 6- to 12-in. layers considered critical to cross-country mobility, a brief discussion of the role of biological activity in influencing soil characteristics is appropriately included in this report.

120. Plants and animals play a more vital role in soil development in the humid temperate climates than in subarctic and tundra, humid tropical, and desert climates. In subarctic and tundra climates, biological activity is minimal; thus, the humus formed by plant decay accumulates and thick deposits of organic soil are common. In humid tropical climates the reverse is true, i.e., biological activity is maximal and the humus is low as the result of rapid oxidation by bacteria. The rapid decomposition and destruction of the humus in these climates is the result of high year-round soil temperatures and copious monthly rainfall. Deserts are found in both temperate and tropical regions and are characterized by low yearly rainfall and sparse vegetal growth. Thus, only minimal organic debris occurs in the surface soil and much of that formed is removed by the wind action. The humid temperate climates are characterized by seasonal weather, higher temperatures, and greater (in the Federal Republic of Germany) precipitation during the summer months, and relatively low temperatures and lower precipitation during the cool months. In these climates bacterial activity is relatively high during the summer and a surface layer of organic material is normal. The thickness of this surface layer is additionally dependent upon variations in plant species, slope, elevation, solar insolation, and other factors, not the least of which is

subtle climatic variations or microclimates. Thick vegetal deposits of peat or semicarbonized plant remains occur in water-saturated locales in humid temperate climates.

121. In addition, the percolation of rainwater through the organic layer creates organic acids, which contribute to the chemical decomposition of the underlying rocks.

PART III: NATURAL AND CULTURAL PROCESSES

Natural Processes

122. Natural processes refer to the mechanisms that integrate the effects of primary genetic factors, i.e., climate, geology, topography, time, and biology, to produce landforms and associated soils (Figure 8). Natural processes also integrate the effect of second-order genetic factors (hydrology (surface drainage and groundwater), local topography (slope and topographic position), vegetation, and local climatic histories) to further refine the character of residual soils and associated soil parameters. Natural processes can be grouped into three fundamental processes: (a) depositional, (b) erosional, and (c) miscellaneous (viz., residual). These are further divisible into individual processes: (a) alluvial, (b) volcanic, (c) colluvial, (d) aeolian, (e) glacial, (f) glaciolacustrine, (g) littoral, and (h) residual. Most of these individual processes can be both depositional and erosional.

123. This classification is expected to work very well for soils throughout the world. All show some geographical preference, being more active in some areas than others. Alluvial processes are much more active in temperate and humid tropical areas than in arid and arctic environments. Littoral processes are at work only along shorelines. Residual processes are widespread but are generally more active on hilly and mountainous areas than on plains. The classification is really a landform-soil association since the various processes produce characteristic landforms which in turn are characterized by discrete soil associations. Often on maps and photography it is not possible to identify soil directly. However, recognition of the processes and the landforms that have evolved due to these processes makes it possible to predict definite soil associations.

124. Problems occur when an effort is made to identify and delineate areas where individual processes are in action since they often overlap or occur simultaneously in the same area. This problem

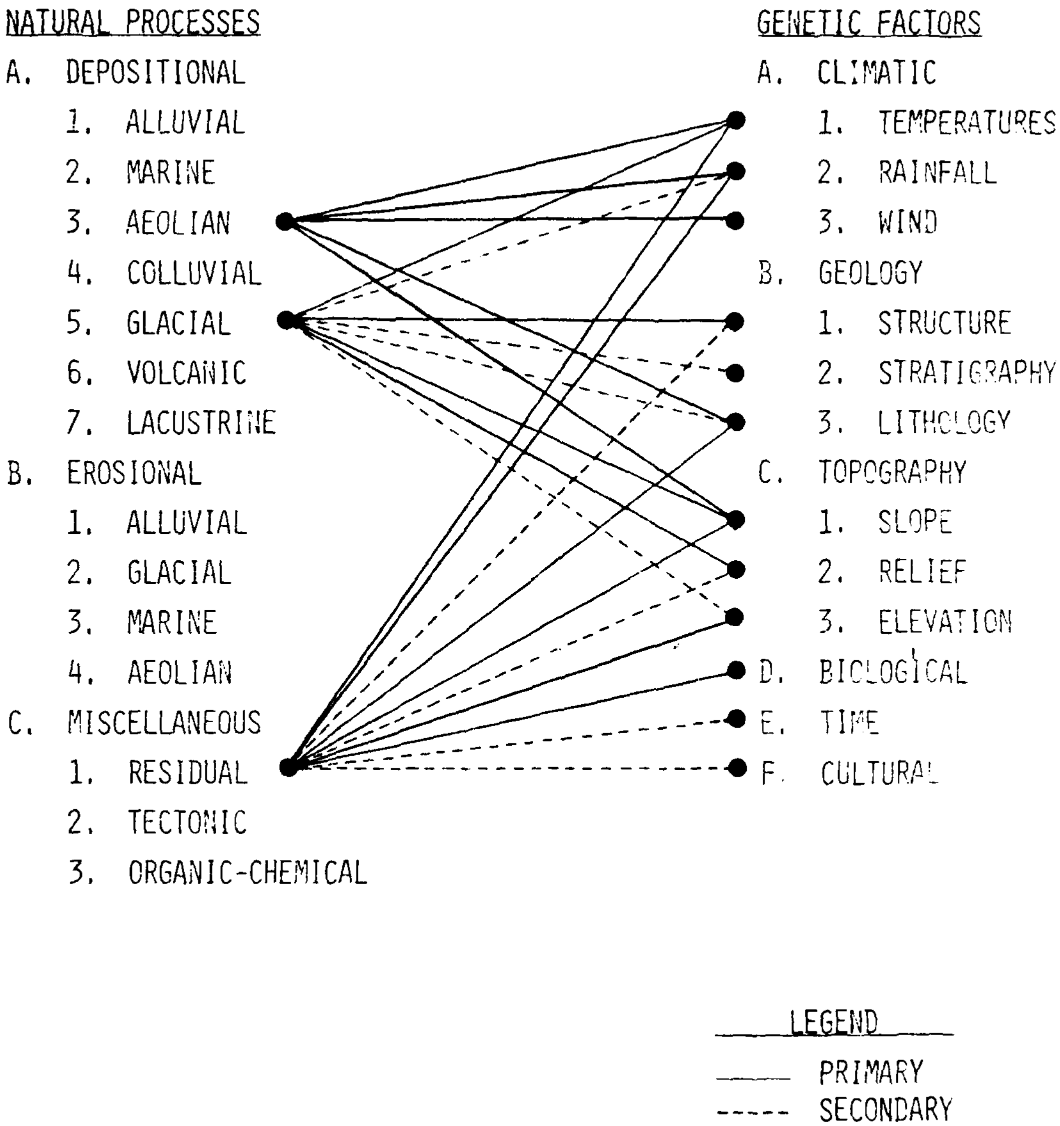


Figure 8. Relationships between natural processes and primary genetic factors

is alleviated as the scale of the maps or photography increases. Another problem occurs when active natural processes are superimposed upon relict patterns that terminated in the geologic past. In areas where two or more processes are in action simultaneously or both active and relict processes must be considered, the dominant (so chosen by a subjective decision) process is given priority.

125. The above natural processes are those that are or have been active in the recent geologic past (Pleistocene to Recent) in the Federal Republic of Germany. They are discussed briefly in the following paragraphs.

Alluvial

126. The alluvial process is a depositional or an erosional process where material or alluvium is eroded, transported, and deposited by the mechanism of running water. The eroded materials are derived from topographically higher source areas. These materials are deposited in predictable patterns. In the Federal Republic of Germany, most alluvial deposits occur within floodplains or at the bases of uplands as alluvial fans and aprons.

Colluvial

127. The colluvial process is a depositional process where material is moved and deposited downslope largely by the force of gravity. These deposits occur on the middle and lower slopes of uplands and are difficult to differentiate from alluvium. Such deposits may be loose, heterogeneous, and incoherent.

Aeolian

128. The aeolian process is a depositional process whereby sand- and silt-size particles are transported from their place or origin by wind action. Dunes and loess are common deposits formed in this way. In the Federal Republic of Germany loess deposits were deposited on the northern flanks of the central highlands during the Pleistocene epoch.

Glacial

129. The glacial process is a process by which advancing ice sheets during the Pleistocene epoch eroded existing soils and rock surfaces, later depositing them during periods of stagnation and retreat.

The deposits are of both stratified and unstratified nature.

Glaciolacustrine

130. The glaciolacustrine process is a depositional process whereby fine-grained sediment transported fluvially by glacial meltwater from its place of origin is deposited in a glacial lake environment; the finer material is deposited near the middle of the lake, the coarser near the shore. Numerous topographically low areas became lakes during the Pleistocene epoch, collecting meltwaters from retreating ice sheets.

Littoral

131. The littoral process is a process by which materials are eroded, sorted, transported, and redeposited by waves and near-shore currents in shallow-water environments.

Volcanic

132. The volcanic process is a process by which molten igneous rock is extruded or blown from depth. Upon cooling, the extruded rock becomes lava, blown-out rock ash, bombs, etc. The weathering of these deposits produces soils varying with reference to the textural and chemical composition of the volcanic material.

Residual

133. The residual process is one by which soils are formed in place by the disintegration and decomposition of parent material, viz., rock. The component of the rock remaining after weathering is the least soluble. The chief residual products are clay and quartz. The depth of residual soils is dependent mainly upon the depth of the water table, time, climate, permeability, and rock type. From an engineering standpoint, residual soils pose little problem, but they are significant to vehicle mobility.

134. As previously stated, this report will be devoted principally to the formation of residual soils by natural processes. Subordinate interest will be directed at glacial and aeolian (loessial) soils due to the availability of field data on these two processes in both the Federal Republic of Germany and the United States. In addition, some discussion will be devoted to cultural processes in evidence

over large portions of the Federal Republic of Germany. Cultural processes are recent in regard to geologic time and thus are superimposed upon older active or relict natural processes in different parts of the Federal Republic of Germany. They have different effects upon the landforms on which they occur, expediting erosion in some instances and deterring it in others. These effects will be discussed in some detail later in this Part.

135. Residual soils formed from parent materials consisting primarily of stable minerals tend to be soils that closely reflect the textural characteristics of the parent material (e.g., quartzite produces sand), while soils formed from parent materials composed principally of unstable minerals will in most instances produce a soil which is finer grained than the original parent material. Since most parent materials contain substantial proportions of unstable minerals, the majority of naturally occurring soils are classified as fine-grained soils in both the USCS and the USDA systems. This is true in humid temperate and humid tropical climatic regions but not in arctic and arid regions where mechanical disintegration is the principal weathering process; and chemical weathering, responsible for the production of most silt- and clay-size particles, is retarded by cold temperatures, the lack of water and vegetation, and minimal biological activity, or, in some cases, all three.

136. The texture of the parent material (i.e., rock) determines to a large degree the depth of the soil profile. Soil profiles are deeper in light-textured (i.e., coarse-grained) soils than in heavy-textured soils. This comparison is valid only in a common climatic region as obviously soil depth is primarily a function of climate. All other factors being equal, soil profiles are deep in tropical climates (tens of metres), moderately deep in temperate (metres), and shallow in arctic and arid regions. This is true because the agents for soil development such as the downward percolation of rainwater, activation of reagents, and displacement of the chemically altered reaction products in the profile are not active in arctic and arid regions.

137. In the humid temperate climates chemical weathering is more

important than physical weathering in the production of residual soils. Of the numerous processes or reactions important in chemical weathering, the most important are solution, oxidation, hydration, and carbonation.

138. Residual soils are widespread throughout the humid climates of the world. They will vary in their characteristics from one geographic region to another as a function principally of their parent material.

139. By definition, residual soils occur directly over the various rocks from which they are formed. The initial coarse regolith which is primarily the product of mechanical disintegration is termed saprolite and is the parent material from which the soil under the influence of other formative factors is formed. The unwary investigator may be easily misled if he unqualifiedly accepts the soil overlying the rock or parent material as residual soil. The seemingly in situ soil may often be the transported product of eroded and transported material of remote origin through the action of other natural processes. For instance, residual soils may be transported downslope by alluvial or colluvial processes and deposited over or mixed with other residual soils, often forming a mixture not representative of the underlying parent material. Loess, or windblown silt, may be transported many miles and deposited on hill slopes or in valley bottoms and form a surface veneer over existing soils. This was especially true during the Pleistocene epoch when silt-size (USCS) material was blown southwards by strong glacial winds from the north and deposited on residual soils on the northern flanks of the central German highlands. In some coastal areas windblown sands may overlie older coastal plain soils. Glacial morainal soils of great thickness may overlie residual soils. Eruptive materials from volcanoes may cover existing soils as in central Germany where Tertiary basalts overlie Mesozoic sandstones and other sedimentaries. Sometimes the reverse is true and residual soils are removed as a result of regional diastrophism. Additional complications result when areas undergo alternating periods of deposition and erosion. These and other situations where several natural processes may be acting simultaneously to produce a composite soil or soils resulting from the

weathered products of interbedded rocks with different lithologies would involve the interaction of far too many variables to be included in the generalized methodology developed for this study. Fortunately, most soil-parent material relationships occurring in nature are relatively uncomplicated and are thus predictable.

140. It was not possible within the scope of this report to precisely evaluate residual soils. Other natural processes may be significant to residual soil development in diverse environmental settings. For example, there were instances where thin veneers of glacial and aeolian (loess) soils were found overlying older in-place residual soils. These instances were determined in the field, and it is doubtful whether soil and geologic maps and documentary data would permit identification of such areas.

141. In areas where several natural processes are active or have been active in Recent time, a judgment is necessary to identify the processes responsible for the development of the upper 12 to 24 in. of soil.

142. Slope is a terrain factor significant in the development of residual soils and their present textural character. On steep slopes residual soil cover is thin, since most of the weathered rock has been removed by gravity or alluvial action. In these cases, the soil that remains is the coarser fraction; the fines are more subject to removal by wind and water action. On steep slopes the incidence of rock outcrops and the occurrence of boulders are greater.

Loessial and glacial soils

143. While the primary focus of this report was directed toward residual soil-forming processes, windblown processes (loess) and glacial processes were given limited consideration for several reasons. Loess and glacial soils are widespread in the northern Federal Republic of Germany. The north German plain is composed largely of glacial and alluvial soils. Unfortunately, there is great diversity in the textural character of glacial landforms, e.g., moraines, kames, eskers, and environments of deposition, e.g., drift, till, and outwash deposits. Geologic literature unfortunately groups glacial landforms and associated

soils by physiography, geologic time, and elevation above sea level and seldom provides maps delineating and characterizing individual landforms and environments of deposition. To the trained and informed analyst, glacial landforms can often be identified on topographic maps and by aerial photography. When this is possible, ranges of soil types can be assigned. Unfortunately, the origins of glacial soils are diverse, being mostly residual soils and rock fragments eroded and carried by the advancing ice sheet. Long, alternating periods of stagnation and retreat result in deposition of numerous glacial landforms, the textures of which are relatable to the environment of deposition and the nature of the source material. Small-scale topographic maps with 20-m or more contour intervals do not permit delineation of individual glacial landforms and thus reduce the value of the map to general interpretation. Large- to medium-scale aerial photography appears the most promising way to identify glacial landforms but, even so, field data would be necessary to establish the range of soil variation. Numerous soil profiles in glaciated portions of central and northeastern United States have resulted in some fundamental insight as to engineering soils associated with glacial landforms. However, the origin of the transported glacial material, coupled with the reality that glaciers move large quantities of material in a fashion not unlike a huge bulldozer, results in almost infinite variations of combined boulder, stone, gravel, sand, silt, and clay deposits exhibiting abrupt lateral and vertical facies changes. Recognition of component landforms in glacial terrain is further impeded by superimposed cultural, viz., agricultural, patterns which conceal or obliterate natural patterns. This is especially true in the Federal Republic of Germany where glaciated regions are extensively devoted to cereal crops.

144. Related to the glacial stages in the Federal Republic of Germany are extensive loess deposits transported south from the glaciated northern regions by prevailing northerly winds and deposited on the northern flanks of the central highlands. These are perhaps the most agriculturally productive lands in all of the Federal Republic of Germany and are thus extensively utilized. Unlike the glacial deposits

to the north, the loess is primarily silt-size particles with subordinate amounts of clay. Profiles analyzed in loess deposits in the United States indicate they are classified as ML in the USCS and SiL (silt loam) in the USDA system.

145. Numerous glacial and loess soil profiles in the Federal Republic of Germany and the United States have been examined and a preliminary variance established. The deposits were laid down during the Pleistocene glacial stages in the two areas during similar climatic conditions. Since the last Pleistocene stage, climates for the two regions have undergone similar evolutions. Identification of source materials for the two regions would be purely speculative at this time and it is doubtful whether the required effort would ever justify the time required if additional effort is directed toward glacial soils. In the case of loessial soils resulting from aeolian transport of silt-size particles from glaciated regions of both countries, origin is not considered to be of primary interest.

146. Other aeolian soils occur in the form of sand dunes along the North Sea. These are areally restrictive in distribution and are considered subordinate in importance to the loess deposits.

147. Other natural processes active in the Federal Republic of Germany are alluvial, colluvial, and littoral. Volcanic deposits in the central Federal Republic of Germany are the result of vulcanism during the Tertiary period. Lacustrine deposits in the Federal Republic of Germany are closely related to Pleistocene glaciation, when meltwaters from stagnant or retreating ice sheets transported fine-grained materials and deposited them in topographically low basins of interior drainage.

148. It should be noted that alluvial, colluvial, glacial, and littoral processes can be erosional as well as depositional, both processes often taking place simultaneously. A good example is alluvial rivers where sandy materials may be eroded from the cut or concave bank and deposited on the convex bank in the form of point bar deposits. Sand may be removed from one locale by the wind and deposited in another.

Cultural Processes

149. In intensively developed countries such as the Federal Republic of Germany, natural processes are disrupted or modified by the cultural activities of man. These activities are most frequently and extensively manifested as agricultural practices. Normal drainage patterns may be completely disrupted or destroyed and precipitation diverted into grain fields. The soil profiles, developed over thousands of years, are the victims of mechanical plows which turn over the soil often to a depth of 6 to 12 in. Natural erosion is contained by field row orientation. Large rock fragments have been continuously removed and stacked at the edges of the fields. Pristine forests have long since vanished from German landscapes and have been replaced by strictly managed stands of conifers and hardwoods.

150. In spite of man's interference, the textural character of the residual soils has essentially maintained its integrity. Through the years, plowing has resulted in a more homogeneous textural profile in the upper 0 to 12 in. where the normal profile reflects removal of fines from the surface layer and transporting them downward to and depositing them in the underlying layer. Near-surface hardpans may be the result of plowing in some instances and may be destroyed by plowing in others, both situations impacting significantly on the soil moisture regime. Soil slopes have been modified over periods of time with more gentle slopes usually resulting.

151. Still, it is assumed in this study that engineering soil types can be predicted in areas of known parent material within acceptable levels of confidence. In European landscapes cultural practices are well known and their influence upon soil development are also predictable although with greater difficulty than in natural situations. Soils on forested upper slopes, on floodplains, and in northern plain areas where soils are unsuited for either agriculture or forests represent near natural conditions. Culturally, the Federal Republic of Germany is more highly developed than analogous regions of the United States. However, correlations of field data from both countries indicated a relatively high level of compatibility.

PART IV: WEATHERING AND SOILS

Weathering

152. Since natural physical and chemical processes and parent material (rock) are the primary factors that produce residual soils in the Federal Republic of Germany and climatically analogous regions of the United States, it is appropriate to include a discussion of both the physical and chemical properties of rock and minerals that produce these residual soils through the mechanism of weathering. A lesser portion of this discussion will deal with the natural processes, glacial and aeolian (loess and sand dunes), which have produced soil covering much of the north and central Federal Republic of Germany.

153. Soils in humid temperate climates occur principally in the north and south midlatitudes. The rate of weathering in these climates is relatively slow in comparison to tropical climates with their continuously warm temperatures and copious rainfall. Soil profiles are generally less than 10 m deep and often less than 1 m, as compared to tropical areas where thicknesses may attain 100 m or more. Deep soils in humid temperate zones suggest formation during Pleistocene or Tertiary climatic regimes. As a general rule, soils occurring in humid temperate climates are not of sufficient thickness to present a problem to most engineering activities. This is not true for vehicle mobility, where the 0- to 24-in. layer is relevant and the 0- to 12-in. layer critical.

154. Initially in the weathering process the pristine rock undergoes physical or mechanical disintegration. The rock will crack or fracture along zones of weakness, mineralogical boundaries, and within a rock type itself due to differential expansion of the component minerals. Generally speaking, coarse rocks of complex mineralogical content will break down more quickly and into smaller particles than fine-grained, homogeneous rocks such as basalt, which will initially weather into large fragments or along hexagonal joint planes.

155. The primary methods by which rock will disintegrate into

progressively smaller particles are heating and cooling, freezing and thawing, and wetting and drying. Particles may first be of boulder size (greater than 24 in.), then stone (10 to 24 in.), cobbles (3 to 10 in.), gravel (2.0 mm to 3 in.), sand (0.074 to 2.0 mm), and silt (0.005 to 0.074 mm). Disintegrated mineral and rock particles seldom progress to clay sizes, which are principally colloidal in size and character, representing chemically altered products of primary minerals. Examples of typical clay minerals are illite, kaolinite, and montmorillonite. Silt is composed of approximately 90 percent quartz and, together with the coarse constituents of the soil, contributes little to soil chemistry. Soils from granite have a higher sand content and a lower clay content than basalt, which is fine-grained and has a high ferromagnesium content.

156. Granites and gneisses contain potassium feldspar and alter upon weathering to the clay mineral kaolinite, while gabbro contains predominantly plagioclase with some ferromagnesium minerals and produces montmorillonite upon weathering.

157. Basically, rocks containing the mineral quartz (SiO_2) are much more resistant than rocks composed of other minerals. Quartz will not decompose chemically and mechanically breaks down to the individual crystals or aggregates of crystals. The crystals are only slightly soluble in water. Quartz-rich rocks usually produce sandy soils. The rate of weathering of sedimentary and metamorphic rocks containing quartz is largely dependent upon the cementing material. Common cementing materials forming the matrix of these rocks (e.g., sandstone, quartzite, schist, gneiss, conglomerate) are iron in the form of limonite or hematite, calcium carbonate, clay, and silica, the latter producing the most resistant rocks.

158. The minerals composing common rocks on the earth's surface vary widely in their rate of disintegration and decomposition and thus profoundly affect the rate of weathering of the rocks. The following paragraphs will discuss some of the weathering characteristics of common minerals and rocks and their relationships with one another. It should be stressed that the relationships presented here apply

principally to humid temperate climates. In the humid tropics, minerals and rocks weather chemically in similar fashion but at a much faster rate. In subarctic and arid climates chemical weathering is of little consequence, the weathered products of rocks resulting almost entirely from mechanical disintegration.

159. A general listing of common rocks in order of their decreasing resistance to weathering in a humid temperate climatic area is presented below. While these rocks were identified in glacial till deposits, their exact age could not be determined. However, their exposure to weathering should be approximately the same, as they belong to the same glacial stage:

quartzite > chert > granite > granodiorite >
tonolite > rhyolite > quartz > latite > dacite >
syenite > monzonite > diorite > gabbro >
trachyte > latite > andesite > basalt > sandstone >
gneiss > schist > siltstone > phyllite > dolomite >
shale > limestone > marl

While this sequence is useful as a general guide, it must be realized that rocks vary extensively in age and in mineralogical composition. In addition, this sequence is valid only in humid temperate and humid tropical regions and must not be considered valid in arid and subarctic regions.

160. The structure of rocks may facilitate or cause resistance to weathering. These properties include hardness, attitude (i.e., horizontally bedded, folded, inclined), bedding thickness, foliation, jointing, texture (especially porosity and permeability), and nature of cementation. Structures in minerals affecting degree and intensity of weathering include molecular structure, chemical composition, hardness, solubility, density, cleavage, crystal size and shape, and type of cementing material. Primary minerals, i.e., those that have undergone no appreciable chemical alteration, compose approximately 70 percent of the soil mass. They usually occur as coarse particles, i.e., the coarse part of the silt fraction, sand, and small gravel. Among the most common of these primary minerals are quartz (12 percent), feldspar (60 percent), micas (4 percent), pyroxene and amphiboles (18 percent), and to a lesser degree apatite and some carbonates. The

feldspars, micas, pyroxenes, and amphiboles actively undergo chemical decay, and, over a long period of time, contribute to the clay fraction of the soil. Hornblende and augite (the most common amphiboles and pyroxenes, respectively) and their weathered alumino-silicate clay products are chemically similar. The primary minerals, which are predominantly silt-size and larger, contribute little to the dynamic chemistry of the soil.

161. Some of the more common rock-forming minerals are listed in accordance with their mode of origin, as follows:

- a. Igneous
  - (1) Quartz
  - (2) Feldspar (Al silicates)
    - (a) Orthoclase - potassium
    - (b) Plagioclase - sodium-calcium
  - (3) Mica
    - (a) Biotite
    - (b) Muscovite
  - (4) Amphiboles
  - (5) Pyroxenes
  - (6) Ilmenite, zircon, titanite, apatite, pyrite, magnetite, rutile, vivianite
  - (7) Olivine
  - (8) Calcite or dolomite
  - (9) Clay minerals - hydrous Al silicates
    - (a) Kaolinite
    - (b) Montmorillonite
    - (c) Illite
  - (10) Limonite and hematite - iron oxides
- b. Sedimentary
  - (1) Sand-type rocks (sandstone and conglomerate)
    - (a) Quartz (as grains)
    - (b) Feldspar (as grains)
    - (c) Mica (as small plates)
    - (d) Clay minerals (flat, clay-size particles)

(e) Limonite, hematite, calcite, and silica--as cementing material

(2) Clay-type rocks (shale and siltstone)

(a) Clay minerals

(b) Quartz (as fine grains)

(c) Mica (as fine plates)

(d) Limonite, hematite, calcite, and quartz (silica)--as cementing material

(3) Lime-type rocks (limestone, dolomite, chalk, marl, coral, coquina)

(a) Calcite (as grains or particles)

(b) Dolomite (as grains or particles)

(c) Quartz (as grains)

(d) Chalcedony or chert (as grains)

(e) Clay minerals

(f) Lime, limonite, hematite, and silica (as cementing material)

c. Metamorphic

(1) Foliated

(a) Coarse-textured (gneiss) - streaked, banded imperfectly, foliated

(b) Medium-textured (schist) - well-foliated, splits easily, rich in mica

(c) Fine-textured (slate, phyllite) - splits into smooth sheets

(2) Massive or nonfoliated

(a) Chiefly quartz (quartzite) - hard and tough, sometimes brittle

(b) Chiefly calcite or dolomite (marble)

(c) Olivine (serpentine) - soft, green

162. With the exception of oxygen, the two most abundant chemical elements in the earth's surface are silicon and aluminum. Apart from quartz, aluminosilicates of various kinds are the most abundant minerals so that the chemical decomposition of rocks is principally concerned with aluminosilicate chemistry. The principal products of the weathering of aluminosilicate minerals are the clay minerals.

163. Quartz is the most resistant of the minerals comprising igneous rocks. Among the feldspars, potassium feldspar is more resistant than plagioclase. Muscovite is more resistant than biotite. Pyroxenes (viz., augite) are more resistant than amphiboles (viz., hornblende).

164. Another factor that must be considered in the rate of decomposition of rocks is acidity. More acidic minerals like quartz and orthoclase are much more resistant than basic minerals like plagioclase and the ferromagnesium minerals.

165. A partial listing of common minerals listed in descending order of their resistance to weathering is as follows: (a) zircon, (b) tourmaline, (c) monazite, (d) quartz, (e) garnet, (f) muscovite, (g) biotite, (h) apatite, (i) microcline, (j) ilmenite, (k) magnetite, (l) staurolite, (m) kyanite, (n) epidote, (o) augite, (p) horneblende, (q) andalusite, (r) topaz, (s) titanite, (t) zoisite, and (u) olivine.

166. The eight most important elements composing common minerals included in major rock types are oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. Other common elements include sulfur, hydrogen, carbon, copper, manganese, nitrogen, phosphorus, and zinc. Rocks composed of many minerals are more prone to physical disintegration due to differential weathering. Dark, basic rocks containing ferromagnesium minerals (especially amphiboles, pyroxenes, olivine, and biotite) produce clay minerals upon weathering chemically and produce clay soils.

167. Clay production usually follows the sequence of rocks to weathering. Gabbro containing ferromagnesium minerals weathers readily, while quartzite is very resistant to weathering and has low potential as a soil former.

168. Some materials are porous and weather more easily than others. In solid rock, geochemical weathering appears to be much the same in all humid climates. Other things being equal, saprolite formation will be faster in the tropics than in temperate zones, but even so, time must be measured in geologic time. Porous materials are already halfway towards being soils and do not form saprolites.

Residual, Glacial, and Aeolian Soils in the Federal Republic of Germany and the United States

169. The following pages will identify and describe common rock types occurring in the Federal Republic of Germany and analogous portions of the United States. Included will be discussions regarding their chemical and physical weathering susceptibility, chemical and physical variations that may result in different textures, and finally the principal soil types developed from these rocks. The discussion will cover glacial and aeolian sites as well, but data from such soils were geographically restricted and were not considered specifically in the development of a methodology for predicting soil texture. Soil type discussions will include statistical data for each rock type (where available) in the form of graphics and tables; data from the Federal Republic of Germany were not used because of their paucity. The statistical presentation covers the 0- to 6-in. and 6- to 12-in. layers, respectively, and both USCS and USDA soil types. Every soil sample was classified in both USCS and USDA terms, whenever possible, i.e., when grain-size curves were determined. For some rocks there are more samples classified as USCS than there are USDA because in such cases only field classification in USCS terms was made (no grain-size determination).

Presentation of statistical data

170. Statistical data will be shown in the figures accompanying the respective discussions of specific rock types (as stated, soil-type data do not accompany every rock type discussed), and the glacial outwash, glacial till, glaciolacustrine, and loessial deposits. The data consist of the percent occurrence of soil type, without regard to slope, and a subdivision of the soil types by their percent occurrence in four slope classes, 0 to 2 percent, 2 to 10 percent, 10 to 20 percent, and greater than 20 percent.

171. Each figure will show a table that includes all pertinent samples, a graphic that represents all but the coarsest soil samples, and a table that shows occurrence by slope class. The graphic will be

a plot of grain-size distribution on a USDA soil textural triangle, for both USDA and USCS soil types, respectively. The USDA triangle is divided into USCS "equivalent" areas for the USCS presentation (see Figure 3). Since the USDA classification does not include gravel sizes, the coarser samples cannot be shown. The graphics are intended to aid in the assessment of the variation in texture that occurs in soil types for a given rock type or origin. The total number of samples used in the statistics will be shown for each tabular and graphic presentation, respectively.

172. Number of sites. A "site" in this study signifies a representative USDA soil profile, e.g., Brandywine fine gravelly loam as reported in "Soil Survey of Madison County, Virginia, USDA Soil Conservation Service." To qualify as a site, a representative profile had to be described in USCS terms as well. The number of sites examined was largely a function of the number of soil survey manuals available to the author. A breakdown of the number of sites offered in this study, according to their origin, follows:

Origin		Number of Sites
Igneous		98
Metamorphic		209
Sedimentary		282
Glacial		507
Aeolian		213
	Total	1309

173. Number of samples. A "sample" signifies a layer of soil (0 to 6 in. or 6 to 12 in.) that was classified in either USCS or USDA terms. The number of samples corresponding to a given site varied widely, according to the information contained in the soil survey manuals. For example, a given USDA-classified layer might be shown to correspond to two or three different (but usually closely related) USCS types or a given USDA representative profile, i.e., a site might have two USDA classifications for the same layer, indicating a range in texture. In many cases, the representative profile was subdivided into layers other than 0 to 6 in. and 6 to 12 in. This fact often resulted in dual USDA and dual USCS classifications for the 6- to 12-in. layer, and a single

classification for the 0- to 6-in. layer. The total number of samples considered in this study was 7924. A breakdown, according to origin, follows:

Origin	USCS 0-6 in.	USCS 6-12 in.	USDA 0-6 in.	USDA 6-12 in.
	Igneous			
Granite	67	84	31	41
Diabase	40	40	24	29
Granodiorite, quartz diorite, and quartz monzonite	23	23	19	20
Gabbro	12	13	7	8
Basalt and andesite	23	26	14	14
Total igneous	165	186	95	112
	Metamorphic			
Rhyolite	11	11	4	4
Gneiss	147	160	79	87
Schist	136	165	93	106
Quartzite	11	10	8	6
Serpentine	17	17	13	11
Slate and phyllite	38	36	22	23
Total metamorphic	360	399	219	237
	Sedimentary			
Siltstone	22	32	18	20
Sandstone	116	112	58	57
Limestone and dolomite	112	118	69	65
Shale	200	222	109	129
Conglomerate	22	24	15	17
Total sedimentary	472	508	269	288
	Glacial			
Glacial outwash	166	243	122	154
Glacial till	547	680	310	390
Glaciolacustrine	227	256	113	152
Total glacial	940	1179	545	696
	Aeolian			
Loess	385	386	225	258
Grand Totals	2322	2658	1353	1591

$\underbrace{2322 \quad 2658 \quad 1353 \quad 1591}_{7924}$

174. Number of samples for slope analysis. The number of samples

used in a given slope analysis was not necessarily the same as the number of samples used in the percentage occurrence analysis for a given origin and layer. This disparity was caused by the lack of consistency between the slope classes used on the slopes cited in the survey manual. The numbers of samples used for each origin, layer, and slope class are shown in the pertinent figures.

175. Explanation of symbols. The letter designations for soil types (and modifiers, USDA) are explained more fully in Figure 1 for USCS soil types and in Figure 3 for USDA types; however, for convenience, they are summarized below:

USCS		USDA	
Symbol	Soil	Symbol	Soil or Modifier
GW	Well-graded gravel	St	Stony
GP	Poorly graded gravel	Sh	Shaley
GM	Silty gravel	Ch	Channery
GC	Clayey gravel	Gr	Gravelly
SW	Well-graded sand	S	Sand
SP	Poorly graded sand	LS	Loamy sand
SM	Silty sand	SL	Sandy loam
SC	Clayey sand	L	Loam
ML	Inorganic silt (LL < 50)*	SiL	Silty loam
CL	Inorganic clay (LL < 50)	SCL	Sandy clay loam
OL	Organic silt (LL < 50)	CL	Clay loam
MH	Inorganic silt (LL > 50)	SiCL	Silty clay loam
CH	Inorganic clay (LL > 50)	Si	Silt
OH	Organic clay (LL > 50)	SC	Sandy clay
Pt	Peat	SiC	Silty clay
		C	Clay

* LL = liquid limit.

Igneous rocks (general)

176. This term includes all rocks solidified from molten material or magma. These may be either plutonic or intrusive rocks which have cooled beneath the earth's surface or extrusive or eruptive rocks which

have emerged from fissures or volcanoes and cooled at the earth's surface. They can be classified as felsic or principally acidic igneous rocks containing a predominance of potassium feldspar with or without quartz and subordinate amounts of biotite, pyroxene, and hornblende. Felsic igneous rocks are predominantly light colored and are more resistant to weathering than mafic rocks. Mafic rocks are principally basic dark and composed of ferromagnesium rocks, viz., olivine, augite, hornblende, hypertene, and biotite, and plagioclase feldspar. Mafic igneous rock containing Fe and Ca weather very easily. Some very dark varieties are composed of hornblende, pyroxene, and olivine without plagioclase feldspar (peridotite, hornblendite, pyroxenite). Some rocks contain both plagioclase and orthoclase (potassium) feldspar, with or without quartz, and may contain small percentages of biotite, hornblende, and pyroxene. These are usually intermediate in color between the felsic and mafic rocks and also intermediate in their weathering characteristics.

177. As stated, igneous rocks are originally in a molten state. The kinds of minerals in the magma determine the composition of the rock when it solidifies either below the surface (plutonic) or above the surface (extrusive). The minerals within the magma crystallize out at different times during the cooling process and follow the sequence portrayed below, if present in the magma:

Olivine → Pyroxene → Hornblende → Biotite → Muscovite

Calcic feldspar → Sodic feldspar → Potassium feldspar → Muscovite

Muscovite → Quartz

178. In the Bowen reaction series, olivine and calcic feldspar are the first minerals to solidify from the solution. If the entire magma crystallized at this point, the resulting rock mass would be gabbro, if intrusive, and basalt, if extrusive. However, if the magma is still molten the next minerals to crystallize are the intermediate feldspars and the ferromagnesium minerals augite (pyroxene) and

hornblende (amphibole). If the magma solidified at this point, the resulting rock would be intermediate between mafic and felsic rocks and would be diorite, if plutonic, and andesite, if extrusive. Should these minerals become separated from the magma at this point the sodic (Na) feldspars and the mica would crystallize. The last mineral in this series to solidify is quartz, which uses the free silica left after crystallization of the other minerals. Granite is a quartz-rich mineral, which, in addition, contains potassium feldspar, biotite, and some plagioclase feldspar. The extrusive equivalent of rocks with this composition is rhyolite. An unanswered question is why granite is by far the most common intrusive rock while basalt with an entirely different mineralogical composition is the most common extrusive rock. The above sequence taken in reverse indicates the resistance of each mineral to weathering.

179. The simplified chart shown in Figure 9 indicates approximate percentages of the principal constituent minerals composing igneous rocks. It does not differentiate between the feldspars. However, it is useful to remember that granite is predominantly potassium feldspar, and diorite contains both potassium and plagioclase feldspars with plagioclase predominating. The feldspar composition of gabbro is almost entirely plagioclase.

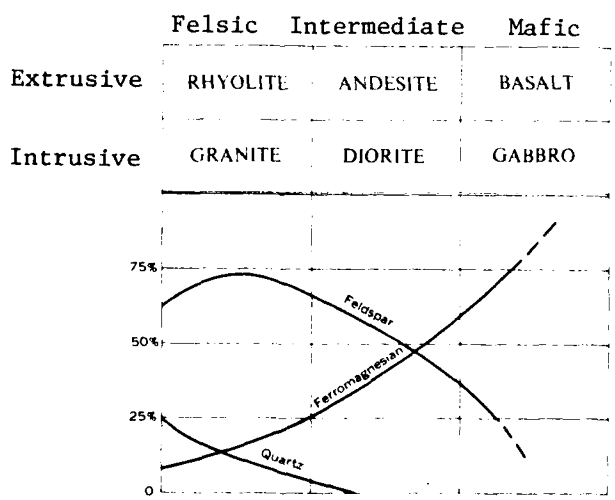


Figure 9. Generalized composition of igneous rocks (from Putnam 1964)

Intrusive igneous rocks

180. Intrusive rocks occur when molten rock solidifies beneath the surface of the earth. They usually, but not always, occur at great depth and usually have a medium- or coarse-grained structure. The size of the individual crystals of quartz and feldspar is due to the slow cooling process. Intrusive rocks occur in a variety of forms. Large masses of solidified rock over 40 square miles are known as batholiths and the bottoms of these structures are usually undetected. Laccoliths are small masses which are lenslike in appearance and usually less than 5 square miles and are fed by a dikelike conduit from below. A sill is a flat mass of magma which has intruded between two preexisting formations and follows their dip. A dike intrudes across preexisting formations or in a vertical sense. Pegmatite dikes are characterized by unusually large crystals (larger than sand) of quartz, feldspar, and rare minerals. They are formed near the edge of the batholiths and are thus the last portion to solidify.

181. Granite. Granite, the most commonly occurring exposed plutonic rock, is composed chiefly of alkali feldspar (orthoclase) and quartz with or without small percentages of biotite, hornblende, and pyroxene. Sodic (Na) feldspar (plagioclase) and muscovite (mica) may also be present in subordinate amounts. The rock is composed of coarse crystals of quartz and feldspar often separated by the dark basic minerals. Grain size affects the weathering of rocks in that coarse-grained igneous rocks weather more rapidly than fine-grained igneous rocks. Thus, soils formed from granite are higher in sand and lower in clay than those formed from basalt. The first mode of weathering of granite is disintegration. The biotite weathers and forms an alteration product which occupies a volume greater than that of the original biotite. This expansion causes stress within, often to depths of 0.5 m, and the rock begins to crumble, forming a coarse-grained residue called "grus." With the passage of time, first the subordinate plagioclase then the potassium feldspar begin to weather and alter to the clay mineral kaolinite. During this period the quartz crystals remain essentially unweathered. The resulting soils then are composed of

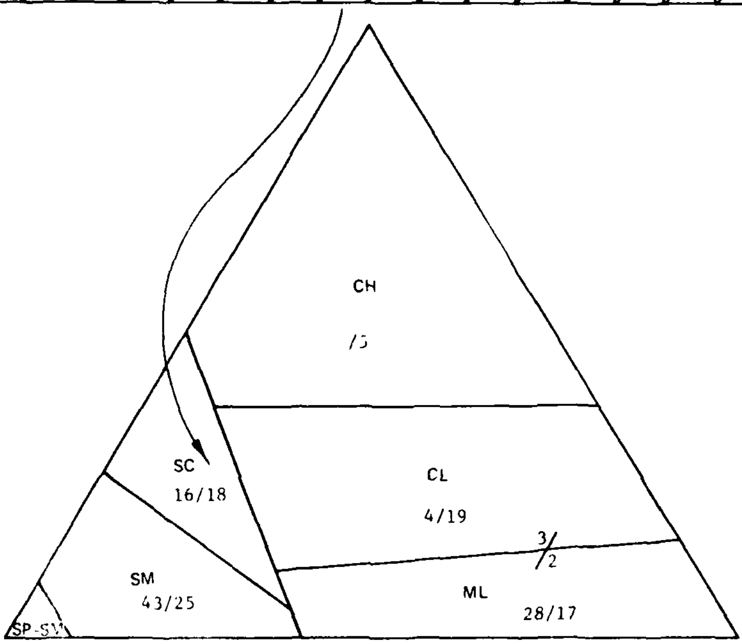
quartz grains of predominantly sand size, although some silt is usually evident, and kaolinitic clay. In USCS terms this would be classified as SM or SC or possibly CL. In the USDA system the soil would be classified as loam, sandy loam, or silty clay loam.

182. The element of time is important in the weathering of granite, but time should not be confused with the geologic age (as determined by radioactive isotopes) the granite may be designated with on the stratigraphic map. It is quite possible that a Tertiary granite may be in a more advanced stage of weathering than a Precambrian granite. The latter may conceivably become exposed to surface weathering agents in Recent time by tectonic processes, while the former may have been undergoing the weathering process for millions of years. The weathering products of the two, by comparison, could reveal dissimilar textural characteristics, the latter containing a higher proportion of sand-size grains. Unfortunately, no quantitative relationship can be made between time and degree of weathering, since during the weathering period climatic changes may have taken place.

183. Approximately 31 sites were examined in residual soils developed from granite (Figures 10 and 11). Generally, the 0- to 6-in. layer was coarser than the 6- to 12-in. layer, and both the 0- to 6-in. and the 6- to 12-in. layers became coarser with increase in slope, since the fines were removed horizontally downslope and vertically from the 0- to 6-in. to the 6- to 12-in. layer. The most common USCS soil type was SM with high percentages of SC and ML (Figure 10). SL (sandy loam) was the most common USDA soil type, followed by loam (L) (Figure 11). The percentage of gravel increased significantly with slope.

184. Syenite and nepheline syenite. Syenite is closely akin to granite, but the quartz content is much lower, although the two may be gradational. The chief feldspar is still potassium (orthoclase) with subordinate amounts of plagioclase. Subordinate amounts of the ferromagnesium minerals are also present. The mature soil weathered from the syenite parent material has a predominantly clayey texture classifiable as a clay loam or sandy clay in USDA terms and CL in the USCS. Syenite is not an abundant rock and does not have extensive outcrops in

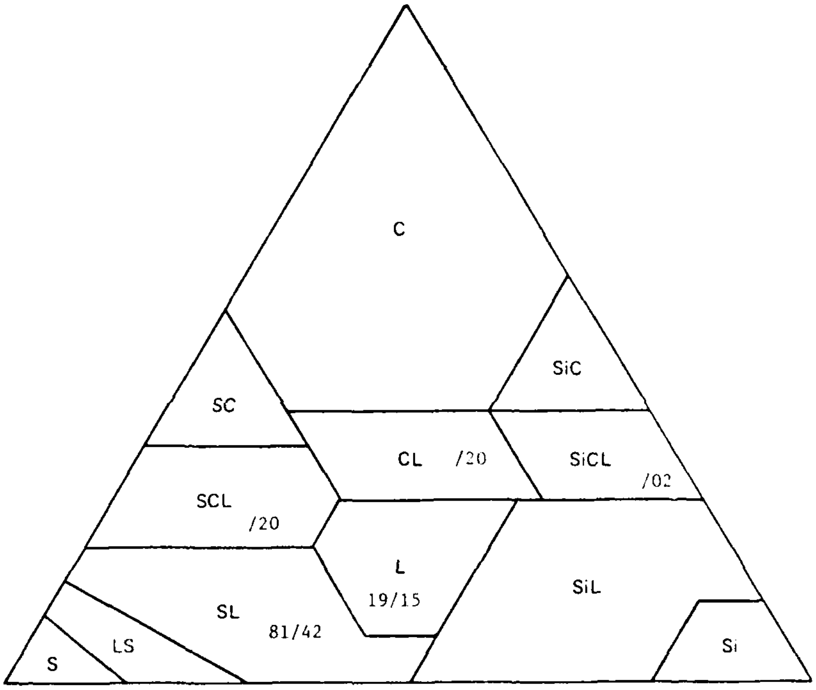
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 67/84																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	3/2	2/2	/	/	/	43/25	16/18	28/17	3/2	/	/12	4/19	/5	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	4/6	/	/	/	/	/	/	/	50/17	/17	40/12	10/4	/	/	/33	/17	/	/	/
2-10	59/63	/	/	03/02	02/03	/	/	/	42/28	15/17	29/12	/	/	/09	08/23	/05	/	/	/
10-20	19/19	/	/	11/11	05/11	/	/	/	42/37	16/16	21/21	/	/	/	05/05	/	/	/	/
> 20	5/8	/	/	20/13	/13	/	/	/	60/38	/25	20/13	/	/	/	/	/	/	/	/

Figure 10. Occurrence of USCS soil types in granite

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 31/41															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/	/	19/12	/	/	81/42	19/15	/	/20	/20	/02	/	/	/	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	3/3	/	/	/	/	/	/	/	33/33	/	33/33	33/33	/	/	/	/	/
2-10	40/40	/	/	/	10/10	/	/	33/33	25/25	/	20/20	20/20	02/13	/	/	/	/
10-20	8/8	/	/	/	50/50	/	/	87/88	13/13	/	/	/	/	/	/	/	/
>20	4/4	/	/	/	50/50	/	/	100/100	/	/	/	/	/	/	/	/	/

Figure 11. Occurrence of USDA soil types in granite

the Federal Republic of Germany or the United States. However, there are significant outcrops throughout the world, viz., Egypt, and it may prove of more relevance to future studies. Nepheline is less resistant to weathering than the feldspars. In the order of decomposibility of the silicates, nepheline-leucite minerals are the most readily decomposed, then olivine and similar minerals (Mg, Fe, Mn, Ca silicates), then pyroxenes and amphiboles, biotite and muscovite, and lastly feldspar.

185. No syenite profiles were examined during this study. It is estimated that less than 1 percent of outcropping igneous rock throughout the world is syenite.

186. Syenites are more resistant to erosion than diorites, monzonites, and gabbros due to the higher percentage of more readily weatherable plagioclase feldspar in those rocks.

187. Diorite. No soils derived from diorite were examined. Diorite is composed principally of plagioclase feldspar with subordinate amounts of one or more of the ferromagnesium minerals which may occupy from 12 to 38 percent of the rock. Quartz present is usually less than 10 percent, but if the quartz present is greater than 10 percent, the rock is known as quartz diorite. The plagioclase is usually the sodic variety called andesine. The rock weathers initially into coarse fragments of sandy texture. The ferromagnesium minerals are first to chemically weather and alter to clay minerals, which, with the feldspar particles and the quartz grains, if present, would form a clayey sand. As the feldspar chemically alters to clay minerals, the texture of the soil becomes finer, so that the final product is a clay soil with varying percentages of quartz, always subordinate to the clay fraction. This final product would be classified as a clay or sandy clay in USDA terms and CL in the USCS. A young profile would contain a high percentage of coarse grains, principally of feldspar, and would be classified as SM or SC in USCS terms and SL (sandy loam) in USDA terms.

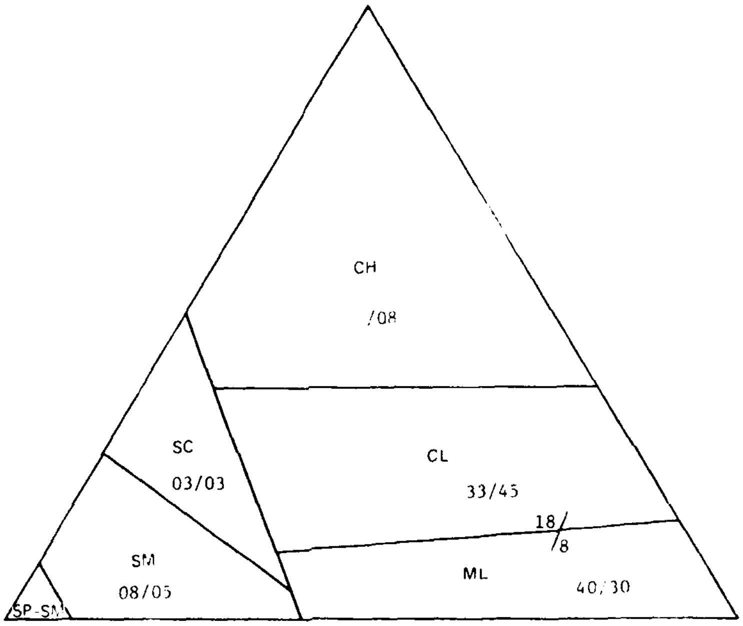
188. Diabase. This analysis considered 24 sites. These are intrusive rocks composed of plagioclase feldspar and the ferromagnesium mineral pyroxene. The texture is finer than that of gabbro and diorite,

being less than 1 mm in diameter. Hornblende and olivine may occur locally. They do not occur in large masses but may occur near the edges of batholiths and laccoliths and in dikes and sills. Phenocrysts of ferromagnesium minerals may occur. They occur throughout the world and are common in the United States and, to a lesser extent, in the Federal Republic of Germany. They are actually transitional in texture between gabbro and basalt and are composed of the same minerals. Initially, diabase weathers mechanically into coarse fragments of sand and gravel with some silt and would be classified as GM, SM, or ML (Figure 12). The ferromagnesium minerals weather rapidly into clay minerals and the still youthful profile would be classified SC, SM, ML, or CL, depending on the ratios of sand, silt, and clay. The mature profile which would include chemically decomposed plagioclase feldspar altered to clay minerals would be primarily a clayey silt (ML) or a silty or sandy clay (CL). The sand content would increase upslope and some SM soils would occur. In USDA terms the soil would be primarily silty loam (SiL) with stone and gravel content increasing upslope (Figure 13).

189. Granodiorite, quartz monzonite, and quartz diorite. Eighteen sites were considered. Granodiorite is a coarse-grained plutonic rock which is gradational in composition between quartz monzonite and quartz diorite. All three rocks contain quartz and feldspars with minor amounts of biotite, hornblende, and pyroxene. In quartz monzonite the ratio of plagioclase feldspar to orthoclase may be nearly equal or the plagioclase may predominate. In granodiorite, the plagioclase clearly predominates and in quartz diorite there is relatively little orthoclase. In any of these three rock types the amount of quartz may vary from 10 to 50 percent. The resistance to weathering would progress from quartz monzonite to granodiorite to quartz diorite. There is little to distinguish the mature profiles of these rock types. It is unlikely that the field investigator could consistently distinguish the often subtle differences between the rocks. They would require petrographic analysis in the laboratory.

190. The durability of the quartz constituent in the profiles is reflected in the 60 percent occurrence of the SM soil type and lesser

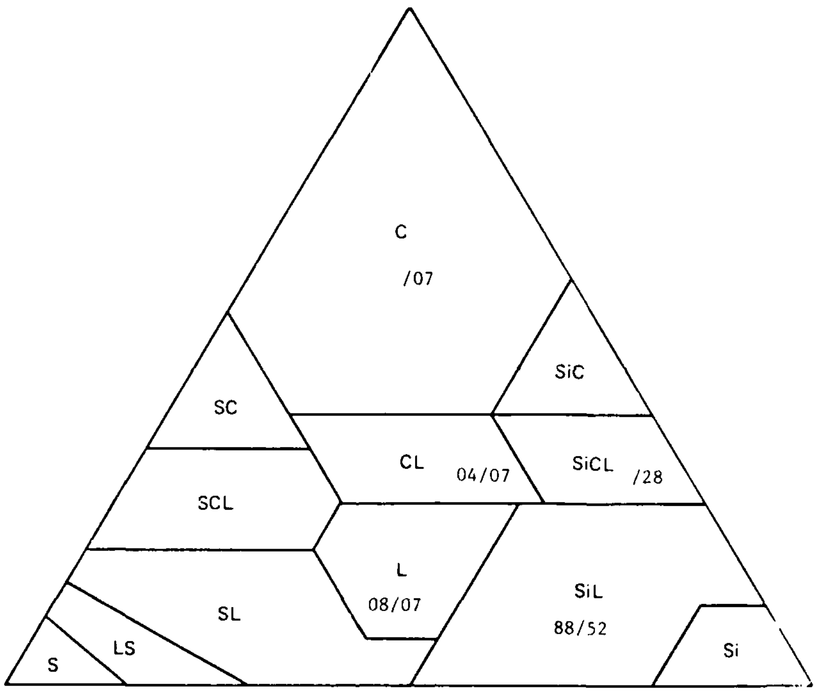
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN 6- TO 12-IN LAYERS 40/40																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	/	/	/	/	/	08/05	03/03	40/30	18/8	/	/03	33/45	/08	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN 6- TO 12-IN LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	15/18	/	/	/	/	/	/	/	/	/	44/35	17/10	/	/05	39/40	/10	/	/	/
2-10	26/22	/	/	/	/	/	/	/	10/09	03/04	44/30	13/04	/	/	33/48	/04	/	/	/
10-20	12/9	/	/	/	/	/	/	/	15/11	/	38/33	/	/	/	38/56	/	/	/	/
> 20	5/4	/	/	/	/	/	/	/	20/	/	40/50	/	/	/	40/50	/	/	/	/

Figure 12. Occurrence of USCS soil types in diabase

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 24/29															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
04/03		04/03	17/14				08/07	88/52		04/07	/28				/07



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	15/18				/09					100/64			/27				/09
2-10	26/22				27/23				18/15	82/54			/23				/08
10-20	12/9			13/11	13/					88/44		13/22	/33				
>20	5/4	50/		50/						100/67			/33				

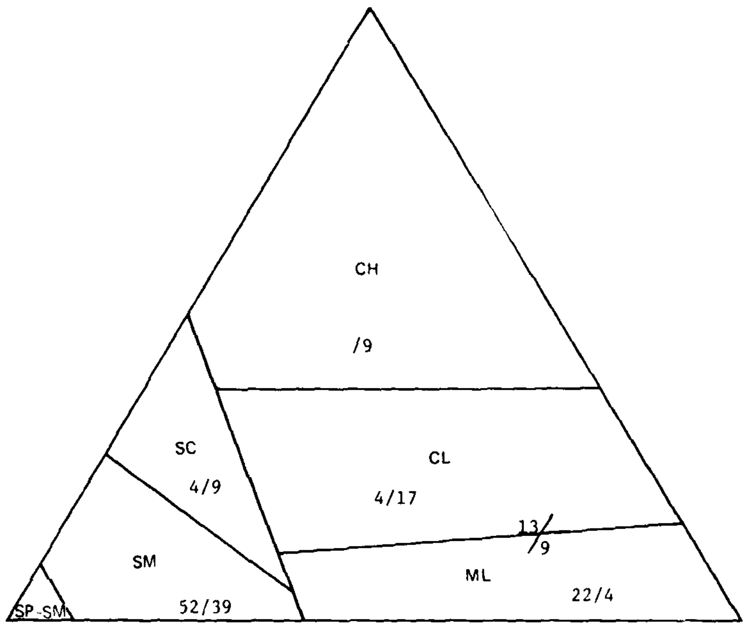
Figure 13. Occurrence of USDA soil types in diabase

percentages of GM, SC, and ML (Figure 14). SM is still the modal type in the 6-to 12-in. layer, although significantly less dominant. The SC and ML percentages remain about the same, but there is a marked increase in the clay fraction due to leaching from above. Very little clay is evident in the USDA classification of the 0- to 6-in. layer, as sandy loam, loam, and silt loam dominate in that sequence. In the 6- to 12-in. layer, the occurrence of sandy loam is still prevalent, albeit diminished, along with the loam and silt loam fractions. Clay loam, silty clay loam, and clay become significant and collectively represent about a 30 percent occurrence.

191. The youthful profile would contain materials principally from mechanical disintegration of the rock. Granodiorite and quartz monzonite would weather initially to coarse particles of both potassium and plagioclase feldspars, quartz, and particles of ferromagnesium minerals. The quartz diorite would contain chiefly plagioclase feldspar, quartz, and particles of ferromagnesium minerals. The initial soil would be sandy and gravelly in texture. The mature soil profile would contain particles of quartz and clay minerals from the feldspars (kaolinite) and the ferromagnesium minerals, principally hornblende, augite, and biotite. Alteration of the feldspars and ferromagnesium minerals to clay minerals would result in finer overall textures; SM and SC soil would be prevalent in most cases, especially on sloping areas, but ML and CL would be nearly as common on lower slopes. In USDA terms sandy loams (SL) and loams (L) would predominate with small percentages of gravels and cobbles (Figure 15). The general overall textures of the soil profiles overlying these rocks are finer in the 6- to 12-in. layer than in the 0- to 6-in. layer in both the USCS and USDA systems.

192. Gabbro. The statistical analysis considered seven sites. Mineralogically, gabbro is the intrusive equivalent of basalt. While basalt is aphanitic, gabbro is a phanerite (individual crystals can be discerned with the unaided eye), the crystals being greater than 1 mm in grain diameter. The principal minerals are plagioclase feldspar and the ferromagnesium minerals hornblende, pyroxene, and olivine. The

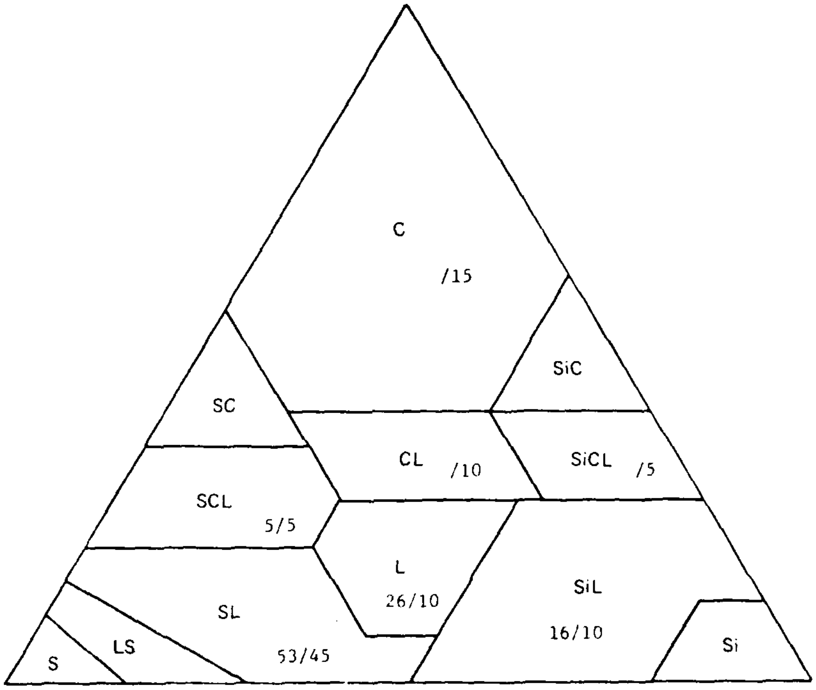
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 23/23																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	4/	/	/	/	/	52/39	4/9	22/4	13/9	/13	/	4/17	/9	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2-10	13/14	/	/	08/	/	/	/	/	31/36	8/7	31/7	/	/21	/	23/21	/7	/	/	/
10-20	12/13	/	/	05/	/	/	/	/	75/62	8/	8/15	/	/8	/	8/15	/	/	/	/
> 20	13/8	/	/	/	/	/	/	/	77/50	15/13	/25	/	/	/	8/	/13	/	/	/

Figure 14. Occurrence of USCS soil types in granodiorite, quartz monzonite, and quartz diorite

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 19/20															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
5/5			5/5			53/45	26/10	16/10	5/5	/10	/5				/15



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2																	
2-10	10/10				50/10			50/40	30/	20/10		/20	/10				/20
10-20	11/11	9/9						82/72	18/19								/9
>20	10/10							70/60	10/10	10/10	10/10						/10

Figure 15. Occurrence of USDA soil types in granodiorite, quartz monzonite, and quartz diorite

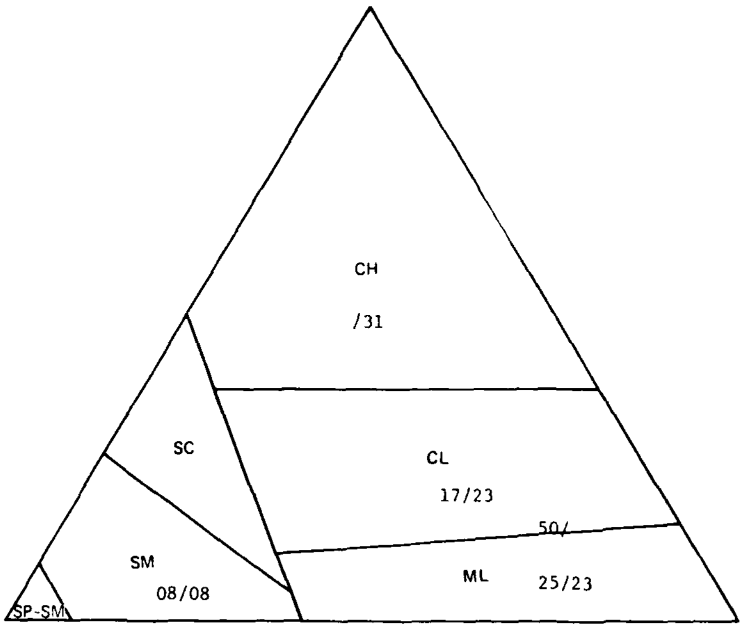
rock is generally dark colored. Biotite, quartz, and orthoclase may be present in relatively small percentages. The unconsolidated debris resulting from the mechanical disintegration of the rock results in sand-size particles, which are soon attacked by chemical agents. This preliminary soil is usually classified as SM or SC in USCS terms (Figure 16). The predominant calcic feldspar and olivine chemically decompose rapidly and form clay soils, which become mixed with the more resistant particles of quartz, orthoclase, hornblende, and pyroxene, and a sandy clay (CL) usually results. In the advanced stages of weathering all of the ferromagnesium minerals have been altered to clay minerals and only the chemically resistant quartz remains. The final product is a clay soil deeply colored by hydrates of iron and containing only resistant rock particles. The thoroughly weathered soil material will have silty clay or clayey silty texture (CL or ML) in the 0- to 6-in. layer and a clayey texture (CL or CH, depending on the type of clay mineral predominating) in the 6- to 12-in. layer. In USDA terms, loam and silt loam (L and SiL) dominate in the 0- to 6-in. layer and silty clay loam and clay (SiC-L and C) in the 6- to 12-in. layer (Figure 17).

Extrusive igneous rocks

193. Rocks which have been poured or ejected onto the surface of the earth are called extrusive. If they are in the form of dense, molten rock they are called lava; if ejected or exploded they take the form of ash, cinders, and fragmental materials. Extruded magma cools rapidly, resulting in a fine texture, although gas pockets and phenocrysts are commonly associated with the solidified material. Extruded igneous rocks, except for glassy varieties, are similar in chemical composition to intrusive igneous rocks.

194. Basalt and andesite. Fourteen sites were used in this analysis. Basalt is the aphanitic equivalent of gabbro and is the most common extrusive rock. Strangely, basalt has little in common mineralogically with granite, by far the most abundant intrusive rock. Basalts are both cryptocrystalline and microcrystalline in texture. The chief minerals are plagioclase feldspar and the ferromagnesium minerals

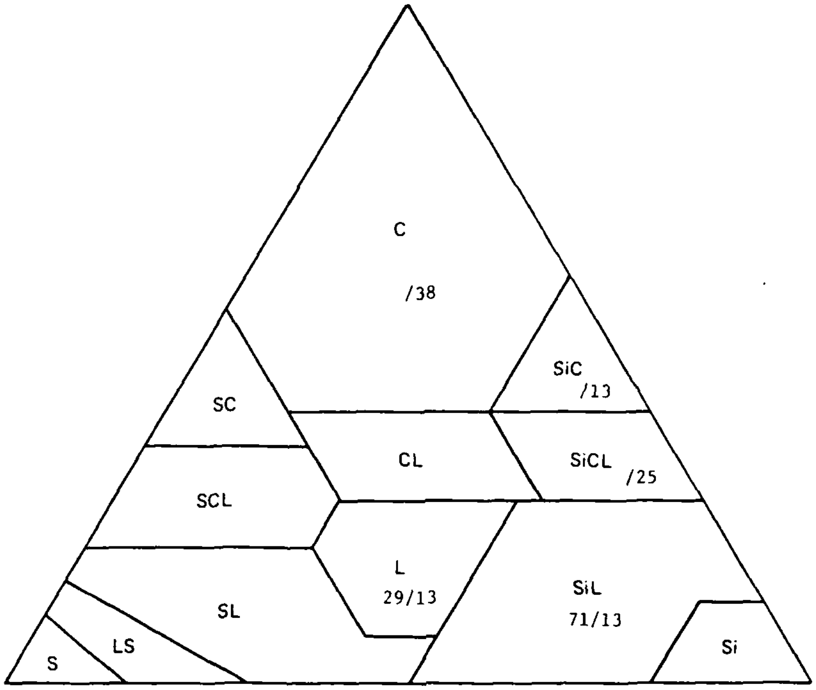
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 12/13																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	/	/	/	/	/	08/08	/	25/23	50/	/08	/08	17/23	/31	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2-10	8/9	/	/	/	/	/	/	/	/	/	25/33	25/	/6	/5	50/33	/22	/	/	/
10-20	5/5	/	/	/	/	/	/	/	20/20	/	30/60	30/	/	/	20/20	/	/	/	/
> 20	1/2	/	/	/	/	/	/	/	/	/	/50	/	/	/	100/50	/	/	/	/

Figure 16. Occurrence of USCS soil types in gabbro

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 7/8															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/	/	/13	/	/	/	29/13	71/13	/	/	/25	/	/	/13	/38



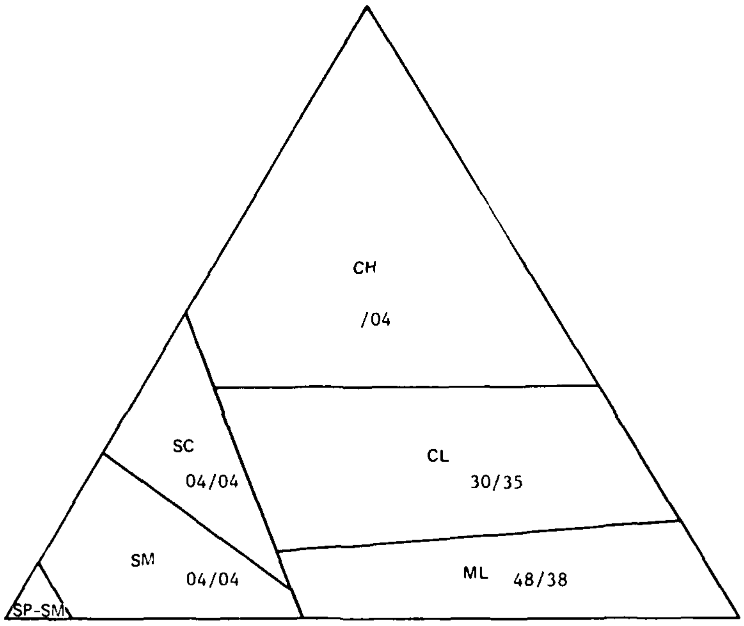
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2-10	6/7	/	/	/	/	/	/	/	33/14	67/14	/	/	/29	/	/	/14	/29
10-20	3/4	/	/	/	/33	/	/	/	/	100/100	/	/	/	/	/	/	/
>20	1/1	/	/	/	/	/	/	/	/	100/100	/	/	/	/	/	/	/

Figure 17. Occurrence of USDA soil types in gabbro

hornblende, pyroxene, and olivine. Being so finely textured, basalt undergoes physical disintegration slowly and then only a thin outer shell is affected. The principal physical weathering is into large fragments or along joint patterns (columnar-hexagonal) or cracks and fissures. Quartz may or may not be present in negligible amounts and contributes little to the soil texture. Soils on Recent basalts tend to be gravelly or stoney silty clays or clayey silts (Figures 18 and 19). The calcic feldspar and the ferromagnesium minerals weather to ferruginous clays in humid temperate climates, often with relatively high percentages of silt particles. The more resistant minerals, such as quartz, nepheline, and potassium and sodic feldspars, weather at a slower rate. The 0- to 6-in. and the 6- to 12-in. layers are very similar, the main dissimilarity being an overall higher percentage of clay particles in the latter. The gravel component in both layers is basalt. Rapid deterioration and decomposition of basalt will result from swelling of montmorillonite clay which occurs as pseudomorphs of olivine phenocrysts or filled vesicles and minute cracks or interstices of the basalt mass. Andesite, a basic lava very similar mineralogically to basalt but lacking olivine, will undergo deterioration due to surface spalling and flaking, the weathering attributed to wetting-drying cycles and air slaking.

195. Rhyolite. Four sites were used in this analysis. Rhyolite is mineralogically the cryptocrystalline equivalent of granite and is composed largely of quartz and orthoclase with minimal quantities of the ferromagnesium minerals biotite, hornblende, and pyroxene (augite) (Figure 20). Rhyolite is generally porphyritic with phenocrysts of quartz and feldspar. It grades into rhyodacite with diminishing quantities of orthoclase feldspar and into trachyte with decreasing quantities of quartz. The initial weathering is probably around the phenocrysts; the rock breaks into large fragments of feldspar and quartz and initially a stony, gravelly soil occurs. With the passage of time, the orthoclase feldspar alters to kaolinite and separates from quartz grains and aggregates which are predominantly silt size. Where fragments of quartz or quartz-feldspar remain, GM soils are evident. Where the

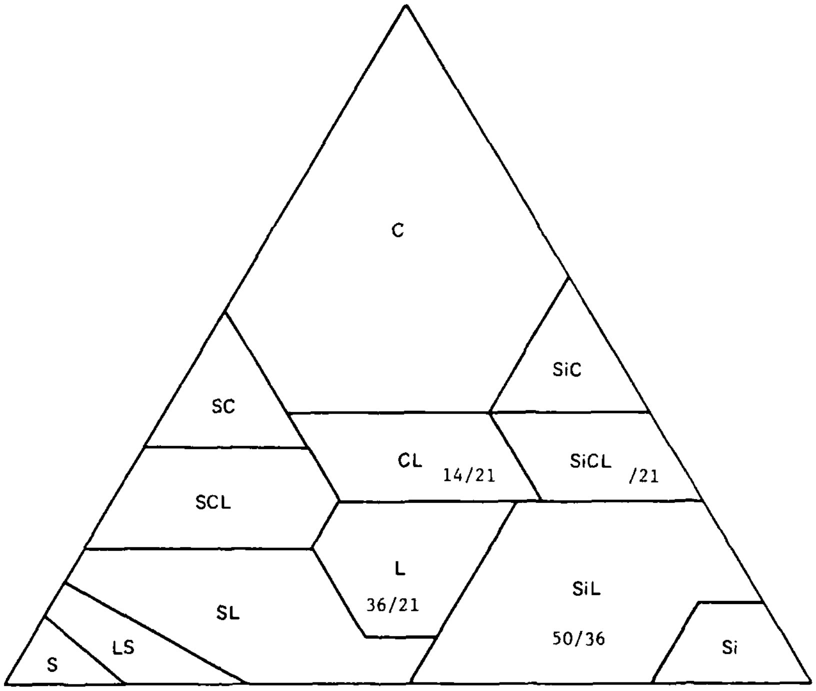
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 23/26																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	09/12	04/04	/	/	/	04/04	04/04	48/38	/	/	/	30/35	/04	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	5/4	/	/	/	/	/	/	/	25/25	25/25	25/25	/	/	/	25/25	/	/	/	/
2-10	22/22	/	/	05/	05/05	/	/	/	05/05	05/05	50/45	/	/	/	30/30	/06	/	/	/
10-20	14/13	/	/	07/08	07/08	/	/	/	07/	07/	43/46	/	/	/	29/38	/	/	/	/
> 20	6/6	/	/	17/17	17/17	/	/	/	/	/	33/33	/	/	/	33/33	/	/	/	/

Figure 18. Occurrence of USCS soil types in basalt and andesite

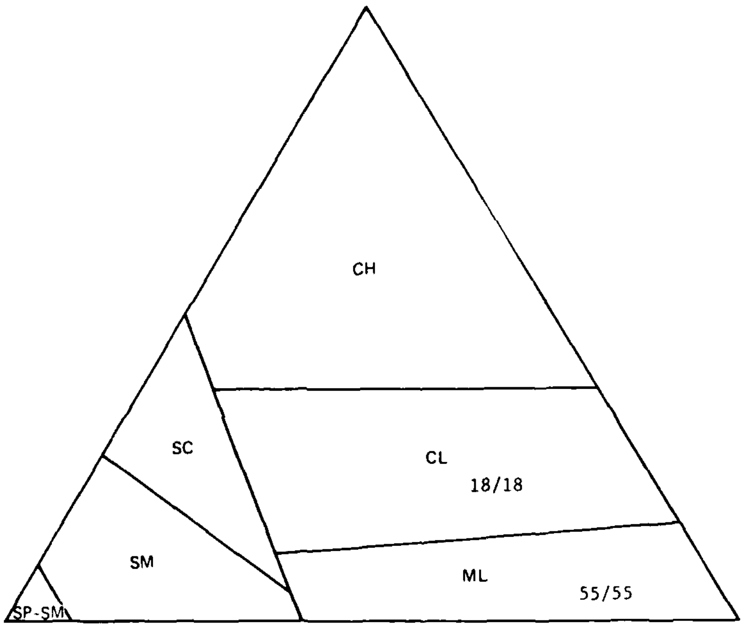
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 14/14															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
04/	/	07/07	14/29	/	/	/	36/21	50/36	/	14/21	/21	/	/	/	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	1/1	/	/	/	/	/	/	/	100/100	/	/	/	/	/	/	/	/
2-10	13/10	/	/	08/10	08/20	/	/	/	23/	62/40	/	15/30	/30	/	/	/	/
10-20	9/6	/	/	11/17	/17	/	/	/	11/17	67/67	/	22/17	/	/	/	/	/
>20	4/4	17/	/	/	17/50	/	/	/	50/25	50/50	/	/25	/	/	/	/	/

Figure 19. Occurrence of USDA soil types in basalt and andesite

PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 11/11																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
		27/27							55/55				18/18				



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2																			
2-10	7/7			29							43				29				
10-20	1/1										100/100								
> 20	3/3			33/33							67/67								

Figure 20. Occurrence of USCS soil types in rhyolite

fine-grained soils predominate, ML soils most often occur; although when the ratio of kaolinite to quartz is high, CL soils occur. These soils classified in USDA terms reveal stony silt loams in the 0- to 6-in. layer and silt loams and stony, silty clay loams and stony clays in the 6- to 12-in. layer (Figure 21).

Metamorphic rocks

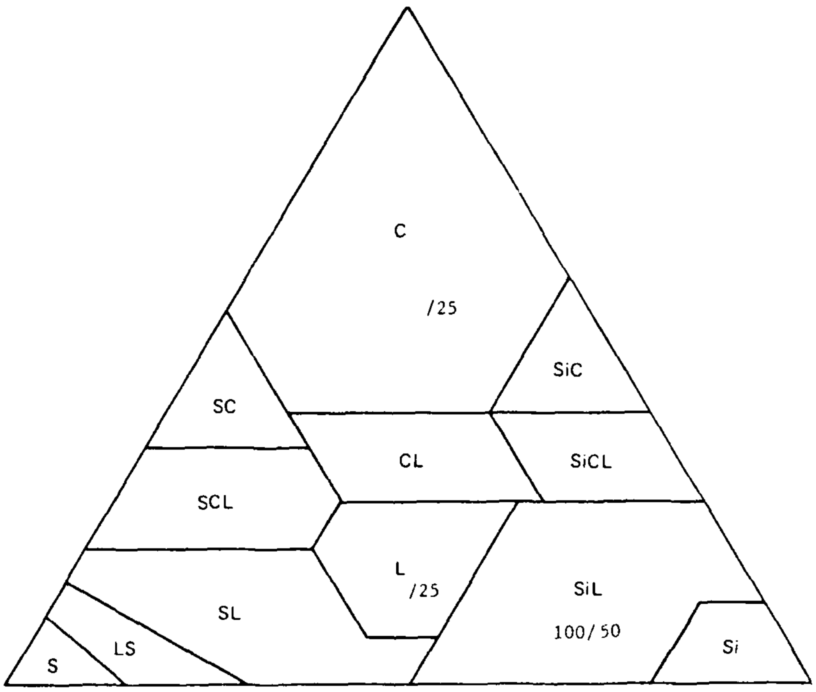
196. Metamorphic rocks are formed from existing igneous and sedimentary rocks that have been altered chemically or physically as a result of intense temperatures and pressures at a depth below the surface of the earth beyond the influences of weathering and cementation. These rocks are characteristically more resistant to weathering than igneous and sedimentary rocks; quartzite is the most resistant of all. However, foliation in metamorphic rocks contributes to their mechanical disintegration. They are thus metamorphosed in an environment both physically and chemically different from that in which they were formed. Common igneous rocks and metamorphic derivatives are listed as follows:

Igneous	Metamorphic
Coarse-grained feldspathic types such as granite	Gneiss, schist, and phyllite
Fine-grained feldspathic types such as felsite and tuff	Schist and phyllite
Ferromagnesium rocks such as dolerite (diabase) and basalt	Hornblende schists
Ultrabasic rocks such as olivine, periodiotite, and pyroxenite	Serpentine and talc schists

Common sedimentary rocks and their metamorphic derivatives are as follows:

Sediment	Sedimentary Rock	Metamorphic Rock
Gravel	Conglomerate	Gneiss and various schists
Sand	Sandstone	Quartzite and various schists
Silt and clay	Siltstone and shale	Slate, phyllite, and various schists
Limy deposits	Limestone	Marble

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 4/4															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
25/25	/	/	25/25	/	/	/	/25	100/50	/	/	/	/	/	/	/25



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2-10	3/2	33/	/	/	/	/	/	/	/	100/100	/	/	/	/	/	/	/
10-20	1/1	100/100	/	/	/	/	/	/	/	100/	/	/	/	/	/	/	/100
>20	2/2	50/50	/	/	50/50	/	/	/	/50	100/	/	/	/	/	/	/	/50

Figure 21. Occurrence of USDA soil types in rhyolite

197. Gneiss. This analysis considered 79 sites. Gneisses are of varied composition derived from both sedimentary rocks and igneous rocks. Those from sedimentary rocks are known as paragneisses and those from igneous rocks are orthogneisses. In both cases, the process of metamorphosis produces a rock of greater durability to weathering than the original igneous or sedimentary rock. Among the sedimentary rocks that become metamorphosed to gneiss are conglomerates, while the most common igneous rocks are the feldspathic types such as granite, syenite, diorite, etc. that are altered into medium- to coarse-grained, banded rocks, which may be contorted as a result of differential pressures. Both muscovite and biotite micas are present mainly along the structure planes. Both potassium and plagioclase feldspars are present, as is quartz, usually in rounded grains or lenses. The gneisses are most prone to mechanical weathering along the cleavage planes due to the comparative weakness of the micas due to hydration. Gneiss soils are initially sandy or gravelly, but as the feldspar (first the calcic, then the sodic, and last the potassium) weathers into the clay mineral kaolinite, appreciable amounts of fines become mixed into the soil. Silty sands (SM) and sandy silts (ML) predominate in the 0- to 6-in. layer. Sandy and silty soils are common in the 6- to 12-in. layer, but the clay fraction results in a marked increase in sandy or silty clay (CL). Again, the degree of weathering will largely determine the soil texture as will the feldspar-quartz ratio. In USDA terms, the 0- to 6-in. horizon is predominantly loam and sandy loam, with subordinate amounts of silt loams. Coarse textures are less dominant in the 6- to 12-in. layer as the clay content increases as a result of enrichment resulting from downward percolation of the fines leached from the 0- to 6-in. horizon. Figures 22 and 23 indicate a propensity toward increase in grain size with increase in topographic slope. Gneissic soils are fertile and sandy, passing into loamy ones as the decay of the feldspar and its alteration into kaolinite progresses.

198. It must be stressed that the term gneiss is a very general one and includes rocks of diverse mineralogical composition and textural characteristics.

AD-A116 939 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/13
NATURAL PROCESSES INFLUENCING TERRAIN ATTRIBUTES. REPORT 1. PRE--ETC(U)
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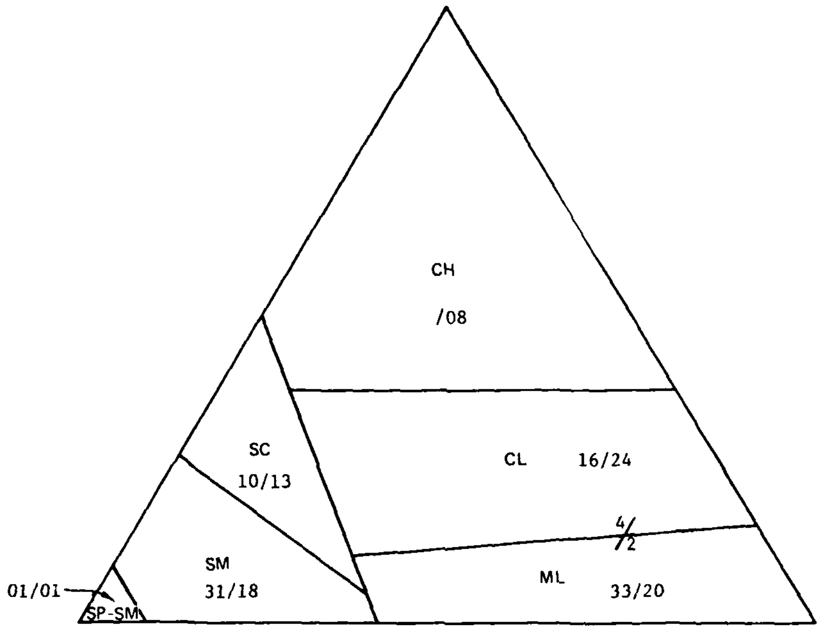
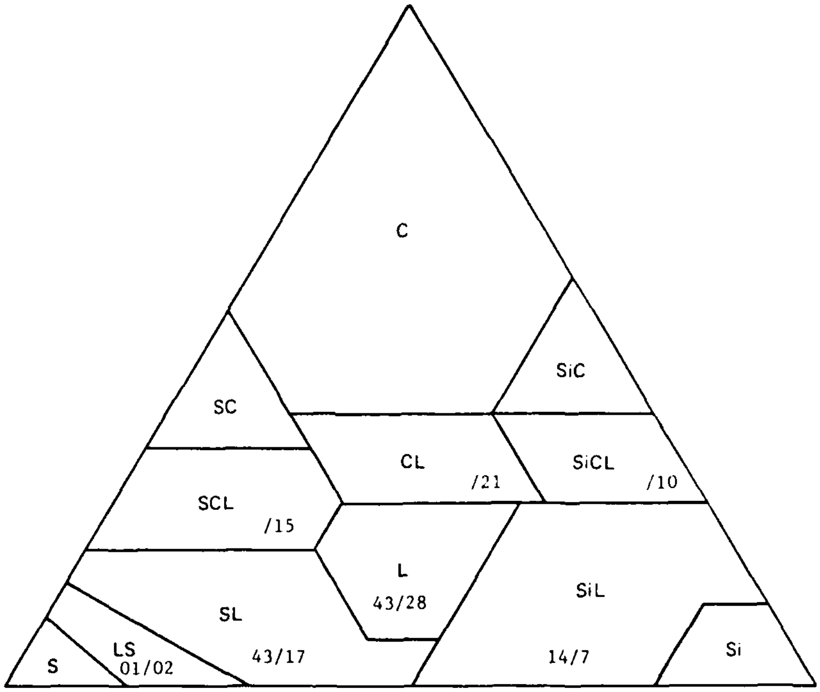
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS. 147/160																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	04/04	01/01	/	01/01	01/01	31/18	10/13	33/20	04/02	/	/	16/20	/08	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	26/26	/	/	/	/	/	04/08	/	23/19	04/08	42/35	/	/	/	27/27	/04	/	/	/
2-10	111/130	/	/	05/05	02/02	/	/	/	33/15	09/12	33/18	/13	/	/	17/25	/08	/	/	/
10-20	43/51	/	/	07/06	02/04	/	/	/	30/27	12/16	33/24	/02	/	/	14/18	/04	/	/	/
> 20	13/16	/	/	/	/	/	/	/	38/31	15/19	38/38	/	/	/	08/13	/	/	/	/

Figure 22. Occurrence of USCS soil types in gneiss

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 79/87															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
01/01	/	04/01	09/09	/	01/02	43/17	43/28	14/7	/15	/21	/10	/	/	/	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	15/17	/	/	/	07/	/	07/12	27/18	47/35	20/12	/12	/06	/06	/	/	/	/
2-10	60/73	/	/	/01	05/07	/	/	48/11	35/19	17/05	/18	/23	/11	/	/	/	/04
10-20	20/25	05/	/	/08	/	/	/	35/28	60/44	05/	/	/08	/12	/	/	/	/
>20	9/7	/	/	/	/	/	/	56/43	44/57	/	/	/	/	/	/	/	/

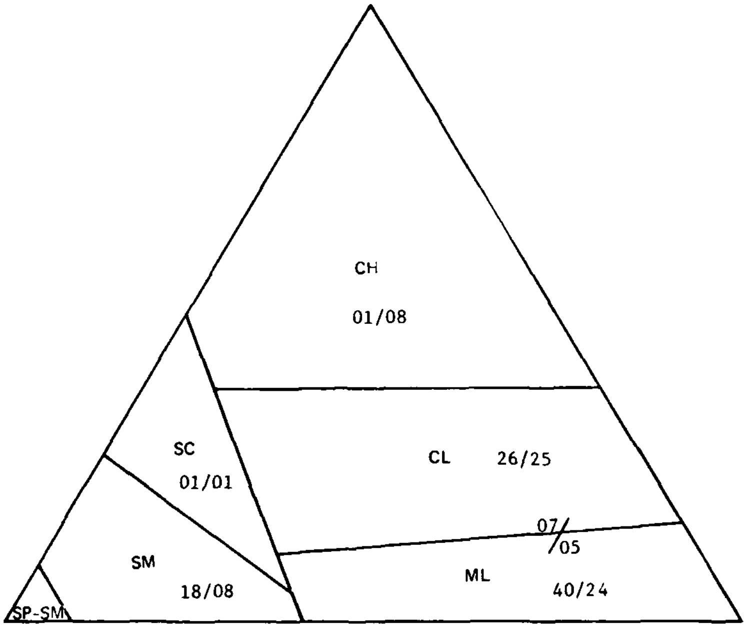
Figure 23. Occurrence of USDA soil types in gneiss

199. Characteristic minerals such as hornblende indicate relatively high percentages of that mineral occurring in the rock and provide a clue to its weathering characteristics. The origin or general composition of the gneiss may be indicated by such terms as granite gneiss or diorite gneiss, enabling identification of the essential minerals.

200. These same modifying terms are equally relevant to schists.

201. Schist. Ninety-two soils were considered. Schists are very similar to gneisses and often grade into them. Of the numerous rocks classified as schists, mica schists are by far the most common. Schists are more finely foliated than gneisses and generally are finer in texture. Sand and silt are the chief textural components of most schists derived from sedimentary rocks. Coarse-grained feldspathic rocks such as granite and diorite may be metamorphosed into schists. They differ from their gneissic counterparts in that they are more finely laminated and have a higher proportion of mica. Fine-grained schists are derived from fine-grained feldspathic rocks such as felsites (fine-grained extrusive or hypabyssal rocks composed chiefly of quartz and feldspar) and tuff (finely compacted volcanic ash). The textural distributions of schist-weathered soils bear strong similarities to those of gneiss (Figure 24). Sandy soils occur more frequently in gneiss profiles than in schist, but not by a large margin. Silty and clayey soils are slightly more prevalent in the schist profiles. These generalizations are also true for the 6- to 12-in. layer. In USDA classification terms, the schist soils show a higher incidence of loam and silt loam soils in the 0- to 6-in. layer and greater occurrences of clay loam and silty clay loams in the 6- to 12-in. layer (Figure 25). In both schist and gneiss soils, the sand content of soil profiles increases with increase in slope; silty soils show no appreciable change with increase in slope in gneiss soils, but a slightly greater increase in schist soils. The clay content of both gneiss and schist soils decreases dramatically with increase in slope. This decrease is attributed to downslope movement of the finer soil particles by alluvial action. There is a greater incidence of gravel and stones on the higher slopes

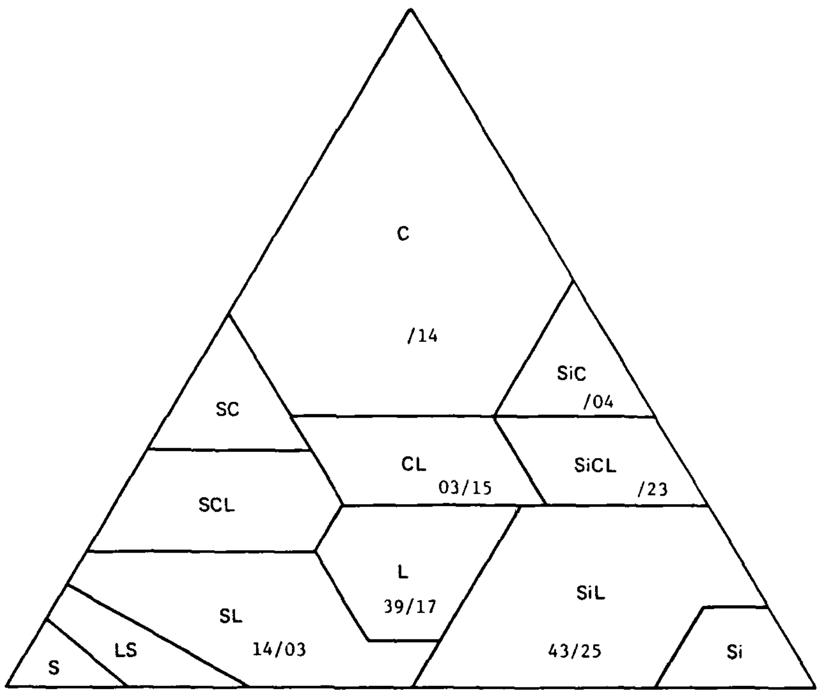
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 136/165																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
		05/07	01/02				18/08	01/01	40/24	07/05	02/19		26/25	01/08			



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	9/11			22/18					11/09		33/36		11/09		22/27				
2-10	127/124			03/03	01/01				14/06	02/01	47/23	06/04	02/23		25/28	01/11			
10-20	48/67			04/06	/03				16/09	/03	55/27	06/	/13		20/27	/12			
> 20	19/23			05/09	/04				25/22	/04	50/35	05/	/04		15/22				

Figure 24. Occurrence of USCS soil types in schist

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 93/106															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
		08/14	01/03			14/03	39/17	43/25		03/15	/23			/04	/14



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	7/17			14/06					43/12	57/71			/18				
2-10	70/74			04/07				14/01	40/09	43/22		03/18	/31			/05	/14
10-20	30/36			07/6	/03			13/03	43/19	40/28		03/14	/28			/03	/06
>20	12/15			17/34	08/13			17/07	42/47	42/33		/13					

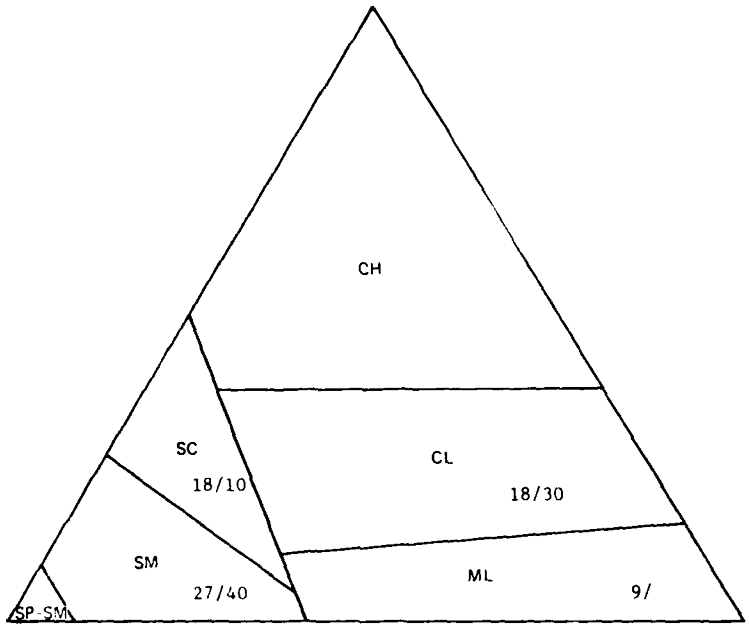
Figure 25. Occurrence of USDA soil types in schist

in schist soils than in gneiss. This can be explained by the fact that coarse-grained rocks physically disintegrate at a more rapid rate than rocks of finer textures.

202. Quartzite. Six soils were used. Quartzite is composed of sand grains so firmly cemented that fracture will usually take place across the individual grains rather than around. Quartzite is formed by the thermal or regional metamorphosis and recrystallization of sandstone, but the distinction between quartzite and quartzitic sandstone in which the binding element is cryptocrystalline quartz or secondary silica is difficult without petrographic analysis. It is, perhaps, the most durable of the common rocks, being little affected by chemical weathering. Some auxiliary minerals such as feldspar occur and new minerals such as muscovite, biotite, kyanite, and epidote also occur resulting from metamorphism. Quartzite is to some degree vulnerable to mechanical weathering, but not to the degree of sandstone, and over a long period of time will break down into sandy and gravelly acid soils. In the 0- to 6-in. layer the USCS shows nearly equal distributions of gravel, sand, and silt, all primarily quartz (Figure 26). The high CL percentage is due to the weathering of the feldspar constituent and to the ferromagnesium minerals resulting from the metamorphism. The proportions of gravel, sand, and silt remain the same in the 6- to 12-in. layer, while the CL soils show a slight increase in clay-size particles due to the enrichment of that layer by the downward percolation of the clay minerals. Figure 27 depicts sandy loam and loamy soils in the 0- to 6-in. layer and sandy loam, loam, and sandy clay loam, all with relatively low clay contents, in the 6- to 12-in. layer.

203. Serpentine. This analysis considered 11 sites. Serpentines are secondary minerals derived from the alteration by metamorphosis of certain ferromagnesium minerals, viz., olivine. They may exhibit a variety of textures from very fine grained to smooth to granular or fibrous. Serpentine is fairly resistant to weathering but ultimately decomposes to brown, ferruginous, clayey soil. The weathering of serpentine is relatively complicated, but initially it alters to

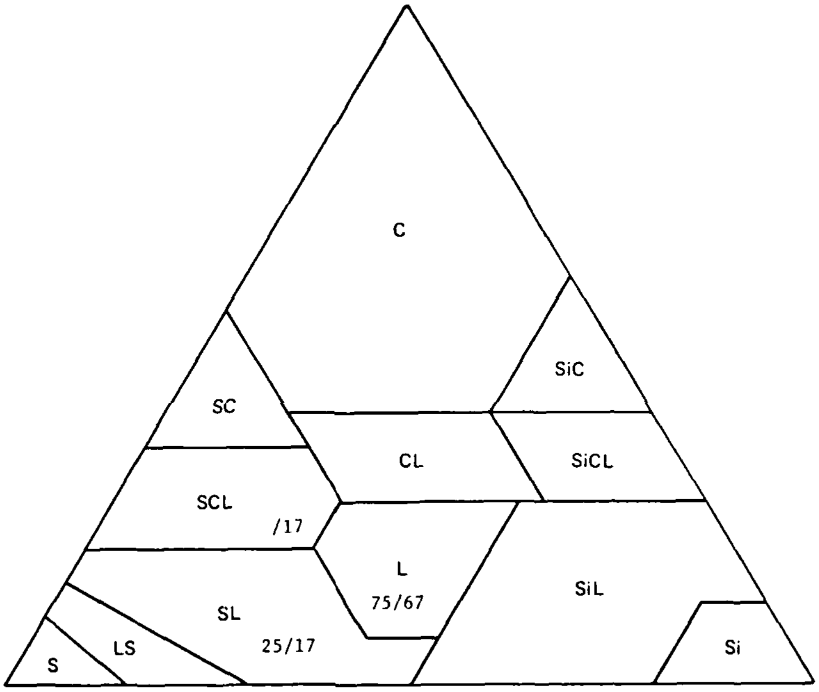
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN. 6- TO 12-IN. LAYERS 11/10																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
		27/20					27/40	18/10	9/				18/30				



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN. 6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	1/2								/50		100/				/50				
2-10	9/7			22/14					33/29	11/14	11/14				22/29				
10-20	1/2								100/50		/50								
> 20	2/3			50/33					50/34		/33								

Figure 26. Occurrence of USCS soil types in quartzite

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 8/6															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
13/17	/	25/17	13/33	/	/	25/17	75/67	/	/17	/	/	/	/	/	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	1/1	/	/	/	/	/	/	/	100/	/	/	/100	/	/	/	/	/
2-10	3/5	/	/	67/33	33/33	/	/	/	100/100	/	/	/	/	/	/	/	/
10-20	2/1	/	/	/	/	/	/	50/	50/100	/	/	/	/	/	/	/	/
>20	4/2	25/30	/	/	/	/	/	50/50	50/50	/	/	/	/	/	/	/	/

Figure 27. Occurrence of USDA soil types in quartzite

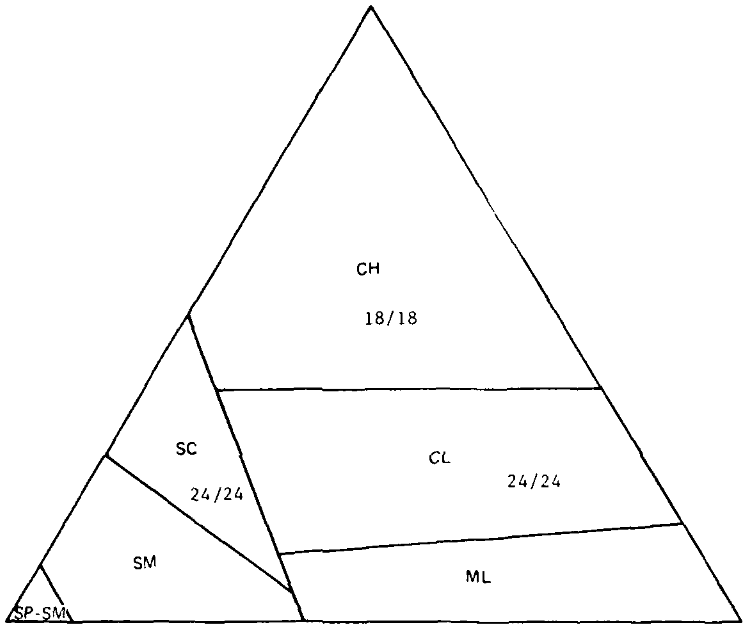
the clay minerals montmorillonite and chlorite, later to gibbsite, and then to kaolinite. The coarse fractions of the USCS histograms are fragments of incompletely weathered serpentine sand and gravels (Figure 28). They combine with the clay fraction to form GC and SC. The main body of the soil is CL and CH. The USDA histograms show a high loam percentage in the 0-to 6-in. layer as well as high percentages of clay loam and clay. The loam content diminishes in the 6- to 12-in. layer and the clay content increases (Figure 29). These soils are gravelly and stony on the steeper slopes.

204. Slate and phyllite. Slate and phyllite were combined in this analysis. Twenty-one sites were considered. Slate and phyllite are similar mineralogically and can be expected to produce similar soil profiles. Slate is metamorphosed shale and thus is formed from clays of many origins. Most slate is so fine grained that the individual particles cannot be seen by the eye or lens. However, some varieties are silty and are gradational to phyllite and schists. Common minerals are quartz, sericite, and chlorite. Kaolinite occurs in low-order slates. Slates possess the quality of fissility; i.e., they can be parted into thin parallel plates. Phyllite is slightly coarser than slate although containing essentially the same minerals. Crystals of biotite, garnet, and staurolite are not uncommon. The A horizons for the slate and phyllite profiles were generally deeper than 12 in. and, as a result, the distributions for the 0- to 6-in. and the 6- to 12-in. layers are very similar. The coarse fraction, i.e., sand and gravel, are likely fragments of disintegrated slate. The ML and CL soils, although percentage-wise in the minority, make up the main body of the soil (Figure 30). The USDA classification shows the soil to be primarily loam and silt loam with lesser fractions of clay loam and silty clay (Figure 31). The silt fraction correlates well with the figure of the parent shale.

Sedimentary rocks

205. Sedimentary rocks have been formed by the consolidation of loose rock particles transported from their place of origin by glacial, aeolian, or fluvial processes. These are called clastic rocks. They

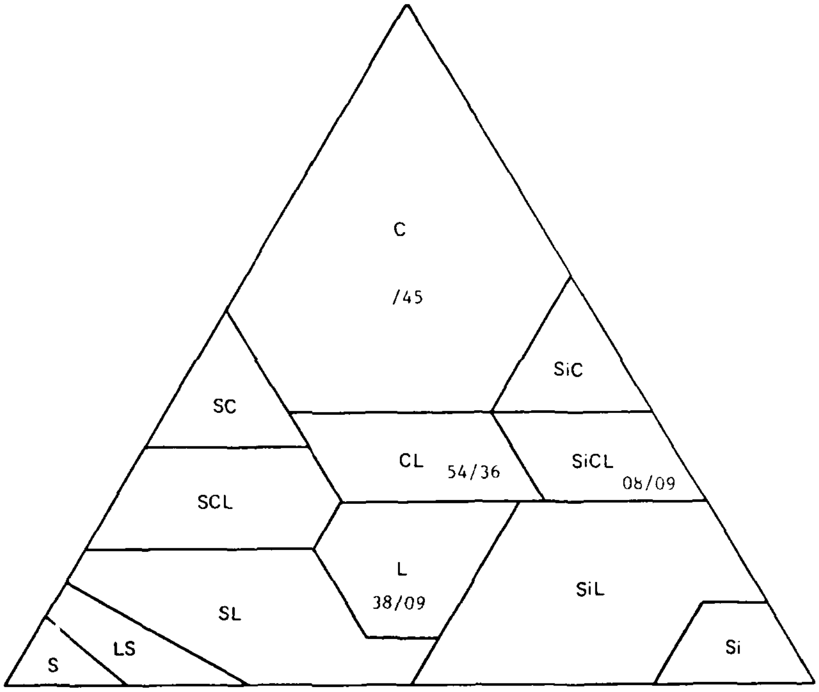
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN 6- TO 12-IN. LAYERS 17/17																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
		06/06	29/29					24/24					24/24	18/18			



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN 6- TO 12-IN LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
0-2																			
2-10	2/2														50/50	50/50			
10-20	12/12			08/08	25/25					17/17					33/33	17/17			
> 20	16/16			06/06	31/31					25/25					25/25	13/13			

Figure 28. Occurrence of USCS soil types in serpentine

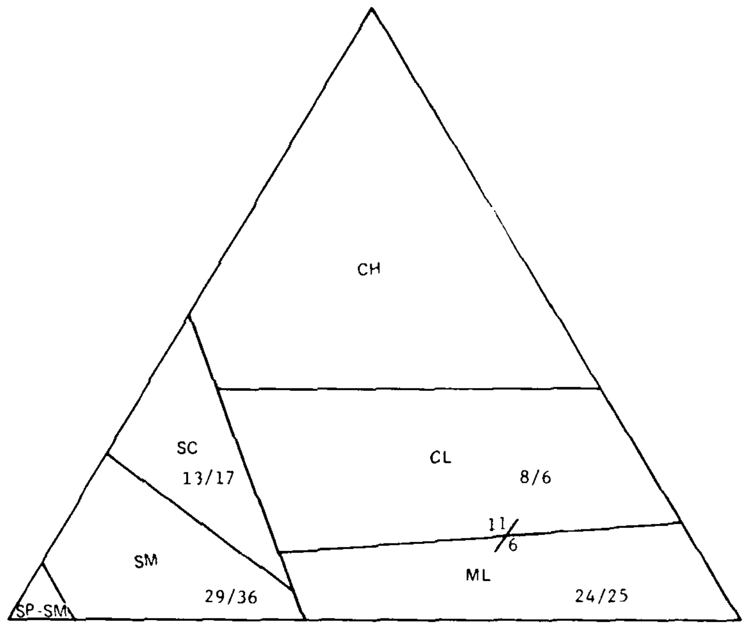
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 13/11															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
23/09			26/36				38/09			44/36	08/09				15/45



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2																	
2-10	3/2								33/			33/50					33/50
10-20	12/8	/13			17/25				25/13			42/38	08/				25/50
>20	16/10	19/10			25/40				31/10			44/40	06/10				14/40

Figure 29. Occurrence of USDA soil types in serpentine

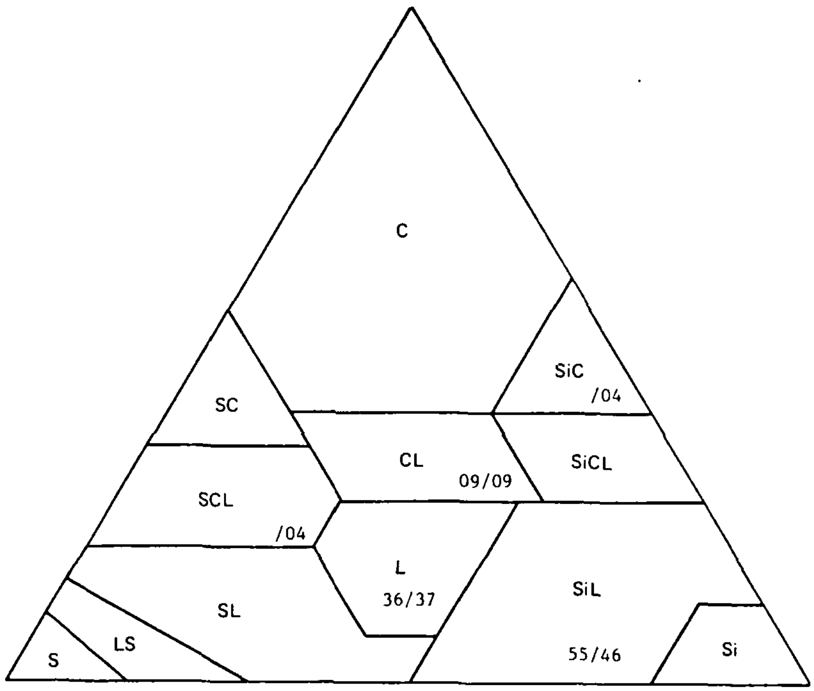
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 38/36																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
		11/11	3/3				29/30	13/17	24/25	11/6	/03		8/6				



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2																			
2-10	27/14			11/14					30/32	11/14	33/32	04/			11/09				
10-20	33/29			09/10	/03				24/21	09/10	33/31	09/07	/03		15/14				
> 20	27/32			04/09	04/03				33/25	19/16	26/28	04/09	/03		12/13				

Figure 30. Occurrence of USCS soil types in slate and phyllite

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: /															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/04	23/22	32/22	/	/	/	36/37	55/46	/04	09/09	/	/	/	/04	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
2-10	11/14	/	/07	27/21	64/21	/	/	/	27/36	64/51	/06	09/07	/	/	/	/	/
10-20	18/17	/	/06	11/18	44/18	/	/	/	28/41	61/47	/06	11/06	/	/	/	/	/
>20	14/17	/	/06	21/28	50/29	/	/	/	29/41	57/41	/	14/12	/	/	/	/06	/

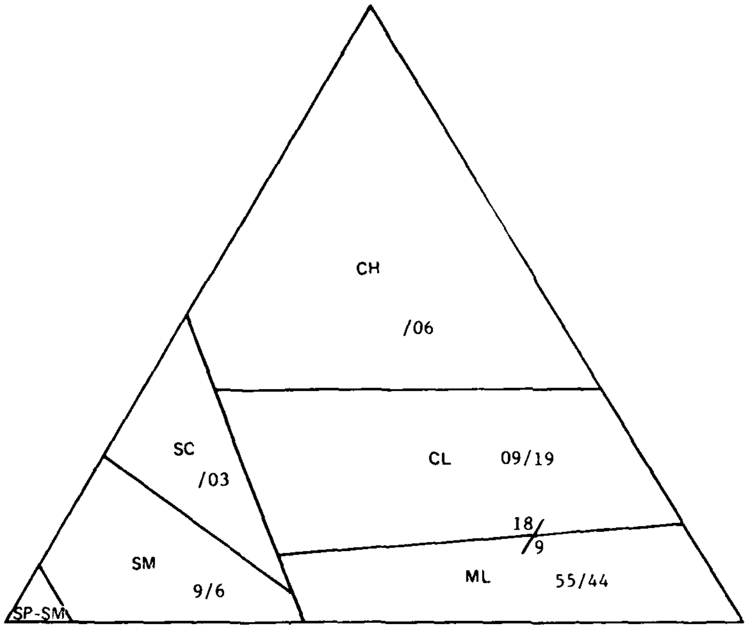
Figure 31. Occurrence of USDA soil types in slate and phyllite

may be formed in place from precipitation such as rock salt, gypsum, and calcite, or they may be of organic origin formed of the tests or secretions of organisms. Common types included in this report are discussed in the following paragraphs.

206. Siltstone. Eighteen sites were considered. Siltstone is predominantly composed of fine grains between 0.005 and 0.074 mm in diameter. It may be transitional into silty shale or silty sandstone. The rock is composed largely of quartz grains cemented in a calcareous, argillaceous, or ferruginous matrix. Sometimes the cementing material is silica and the rock formed is similar to quartzite. When originally cemented with lime, the weathered soil is composed almost entirely of silt, the lime having been removed in solution over a period of time. The ferruginous cement stains the grains a rust color; however, the iron percolates downward into the lower layers. Siltstones that are gradational to sandstone and shale will obviously have percentages of sand and clay. The sandy soils would most likely be classified in USCS terms as SM or ML while the argillaceous siltstone would be classified as CL (Figure 32). In instances where fragments of siltstone occur in the soil, they may be classified as GM. In the 6- to 12-in. horizon, ML soils dominate. Where the sand content is high, GM and SM occur, and where the clay content is high, CL and CH occur. If the clay mineral montmorillonite occurs, the soil may be classified as CH or MH even though the sample may be 80 to 90 percent silt. In USDA terms, the dominant soil type in both the 0- to 6-in. and the 6- to 12-in. layers is silt loam (SiL) (Figure 33). Where the clay content is high, silty clay loams (SiC-L) and clays (C) are evident.

207. Sandstone. The statistical analysis considered 57 sites. All of these were classified in USCS terms and 51 of these in USDA terms. Sandstones are primarily composed of quartz ranging in diameter from 0.074 to 4.76 mm. Hornblende, augite, feldspar, glauconite, and mica are frequent occurrences, but their percentage of the total volume is small. Black sands composed entirely of fragments from basic volcanic rocks occur locally on beaches near volcanoes. Similar to siltstone, the quartz sand grains are cemented with silica, calcium carbonate,

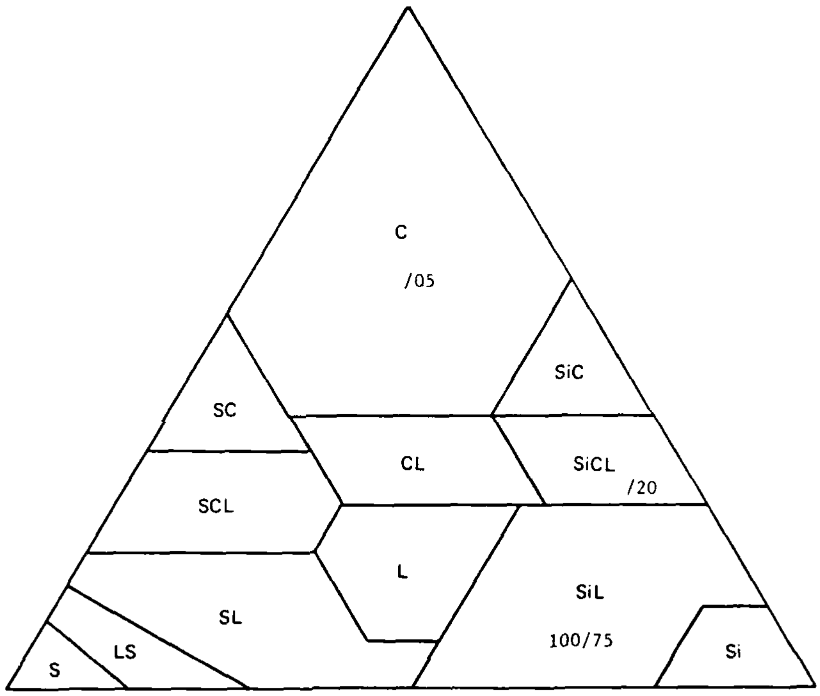
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 22/32																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	09/09	/	/	/	/	09/06	/03	55/44	18/09	/03	/	09/19	/06	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	6/5	/	/	/	/	/	/	/	14/17	/	67/50	14/17	/	/	14/17	/	/	/	/
2-10	11/12	/	/	/08	/	/	/	/	/	/	67/46	08/	/08	/	25/31	/08	/	/	/
10-20	14/21	/	/	/08	/	/	/	/	/08	/04	60/33	07/08	/04	/	33/25	/08	/	/	/
> 20	11/14	/	/	17/13	/	/	/	/	/	/	58/53	08/07	/	/	17/27	/	/	/	/

Figure 32. Occurrence of USCS soil types in siltstone

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS. 18/20															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	06/	19/30	/	/	/	/	/	100/75	/	/	/20	/	/	/	/05



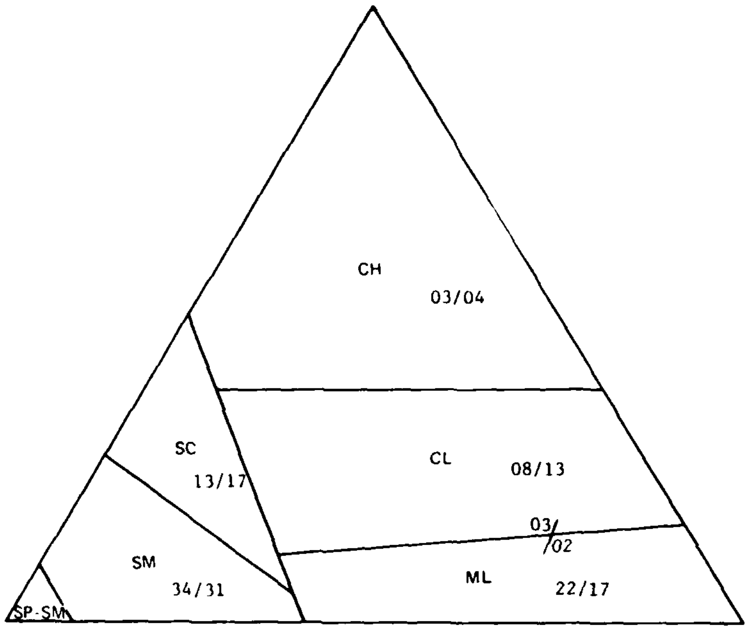
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	4/4	/	/	25/25	/	/	/	/	/	100/100	/	/	/	/	/	/	/
2-10	8/13	/	/	13/08	/	/	/	/	/	100/62	/	/	/31	/	/	/	/08
10-20	9/9	/	/	/11	/	/	/	/	/	100/44	/	/	/44	/	/	/	/11
>20	7/6	/	14/	14/67	/	/	/	/	/	100/100	/	/	/	/	/	/	/

Figure 33. Occurrence of USDA soil types in siltstone

clay, and iron oxides. During the weathering process, the lime and much of the iron oxide cement are removed and a sandy, even-textured soil (SP) remains. The clay minerals are largely removed from the surface horizon and transported laterally or downward with the incidence of rainfall. The silica-cemented sandstone is the most resistant and the initial breakdown is primarily mechanical, although silica is slightly soluble in water. When exposed to air, soft, friable sandstones often become case-hardened, which actually slows the rate of weathering. Sandstones weather to sandy soils, most often SM and SC, in USCS terms (Figure 34) and to sandy loam (SL) in USDA terms. Appreciable amounts of gravel and stones occur increasingly upslope; these soils are classified as GM or GC. The fines decrease upslope, as would be expected, by downward leaching and lateral displacement downslope. The soil profiles in the Federal Republic of Germany in areas of residual soil from sandstone were predominantly classified as SM in the 0- to 6-in. and 6- to 12-in. layers. Unfortunately, the sampling was restricted to sandstone profiles in a relatively small area. Sandstones in other parts of the Federal Republic of Germany would undoubtedly reveal some degree of textural variation.

208. Limestone and dolomite. The analysis considered 65 sites in limestone and dolomite (combined). All of these were classified in both USCS and USDA terms. Limestone may be composed entirely or predominantly of calcium carbonate ($CaCO_3$). Limestone is by far the most abundant carbonate rock. Others include dolomite ($Ca,MgCO_3$), siderite ($FeCO_3$), magnesite ($MgCO_3$), and breunnerite ($Mg,FeCO_3$). Of these four, dolomite is second only to limestone in abundance. Limestones may range from aphanitic to phaneritic and may be either crystalline or amorphous. Some are organic, composed entirely of the calcium carbonate tests of mollusks, brachiopods, or foraminifera. They are also inorganic, often containing substantial amounts of clay, sand, silt, bitumens, and chert in the form of nodules. During weathering in humid climates, the calcium carbonate content of the rock is dissolved and carried away in solution. Prior to chemical weathering, however, the limestone is broken down by disintegration or mechanical weathering

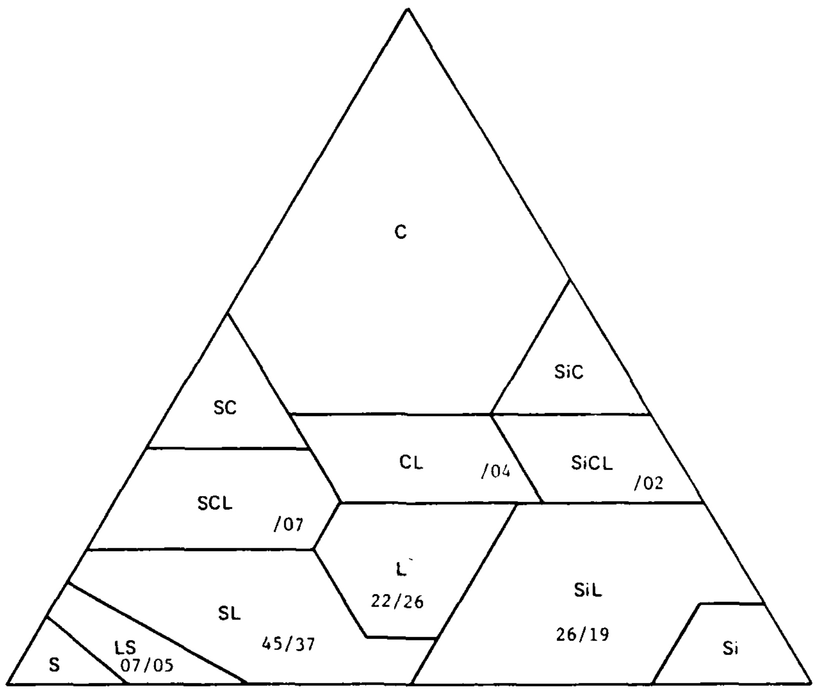
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN/6- TO 12-IN LAYERS 116/112																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
/	/	13/13	03/03	/	/1	/	34/31	13/17	22/17	03/02	01/01	/	08/13	03/04	/	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN/6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
0-2	3/5	/	/	/	/	/	/	/	/20	/40	67/	/	/	/	33/40	/	/	/	/
2-10	69/66	/	/	13/11	05/03	/	/02	/	30/35	13/17	20/17	3/2	/03	/	17/12	/02	/	/	/
10-20	37/27	/	/	08/07	/	/	/	/	49/48	14/26	16/15	/	05/	/	05/04	03/	/	/	/
> 20	16/10	/	/	19/30	06/10	/	/	/	50/40	06/10	/10	/	13/	/	/	06/	/	/	/

Figure 34. Occurrence of USCS soil types in sandstone

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 58/57															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
07/07	/	26/26	07/07	/	07/05	45/37	22/26	26/19	/07	/04	/02	/	/	/	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	3/2	/	/	/	/	/	/	/	67/50	33/50	/	/	/	/	/	/	/
2-10	39/37	/08	/	31/16	08/08	/	/05	41/27	26/32	33/19	/08	/05	/03	/	/	/	/
10-20	18/19	/11	/	11/21	06/05	/	11/11	78/63	06/05	06/16	/05	/	/	/	/	/	/
>20	8/5	/	/	26/60	12/	/	25/40	/40	63/20	13/	/	/	/	/	/	/	/

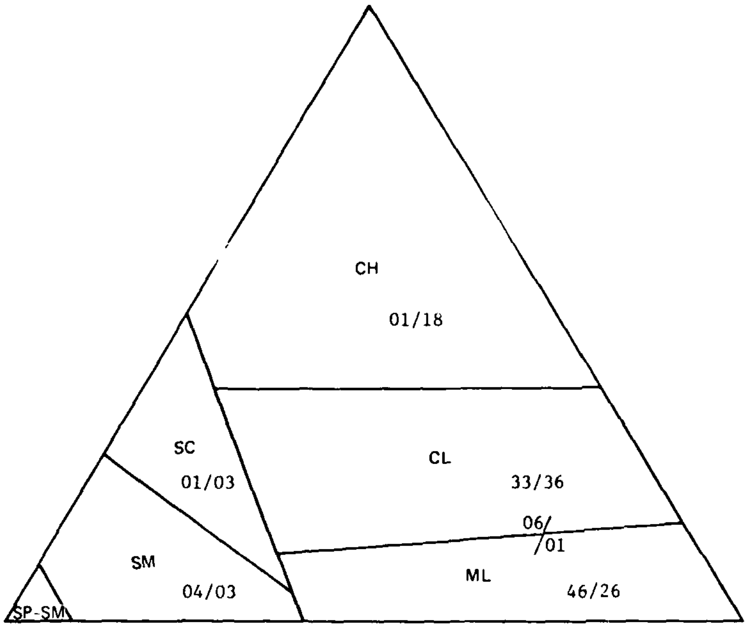
Figure 35. Occurrence of USDA soil types in sandstone

of the surface rocks into small fragments. A shallow, stony, immature soil is formed in this way. After the limestone has dissolved and has been carried away, the impurities in the rock, (e.g., sand, silt, and clay) become the soil-forming materials. Usually these impurities comprise less than 10 percent of the limestone, but they accumulate rapidly during the soil development as the calcium carbonate is dissolved and carried away by water. This makes the actual depth of weathering difficult to assess. A known example reveals 3 m of residual clay representing 130 m of the original limestone. Ironically, in arid climates, limestone is one of the most resistant rocks to weathering.

209. The term limestone, without a modifier identifying the nature of the impurities, provides no clue as to the textural composition of the residual soil. In USCS terms, the majority of the profiles examined revealed clayey silt (ML) and silty clay (CL) textures in the 0- to 6-in. layer (Figure 36). The small percentages of SM and SC can probably be attributed to arenaceous impurities in some of the profiles. The GM and GC are probably immature soils with a high gravel content. The sand and gravel components in the 6- to 12-in. layer can be explained in the same way as the surface layer. The increase in CH soil in this layer can be attributed to the downward percolation of clay particles. In USDA terms, most of the profiles analyzed in the 0- to 6-in. layer were silt loams or silty clay loams (Figure 37). Silt loam is still the most commonly occurring soil type in the 6- to 12-in. layer; however, enrichment of this layer with clay particles has resulted in substantial increases in silty clay loam and silty clay soils. The abundance of clay particles in the profiles suggests contemporaneous deposition of clay and precipitation of lime in the same marine environment. Much of the cobbly and stony components of the profiles can be attributed to the presence of chert in some limestones. The chert has its origin from the precipitation of silica in voids in the limestone over an extended period of time.

210. As previously stated, the term limestone without a modifier forces the analyst to estimate the textural composition of the residual

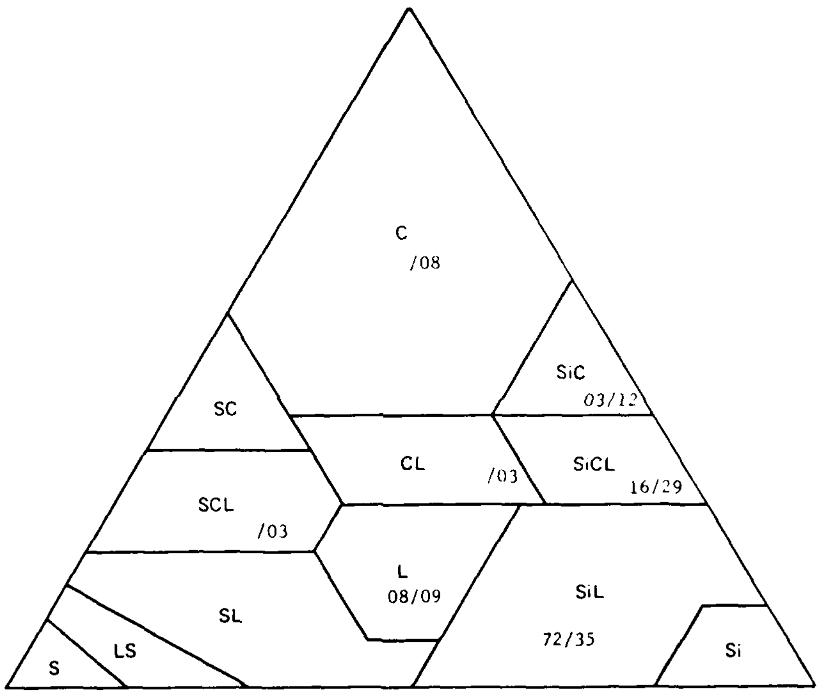
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
N MBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN LAYERS 112/118																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
		04/03	02/02				04/03	01/03	46/26	06/01	04/08		33/36	01/18			



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	25/24								04/04		52/42				44/50	/04			
2-10	63/69			/01					03/03	01/03	50/25	4/1	02/12		37/39	02/14			
10-20	25/27			08/04	04/04						48/19		08/19		32/33	/22			
> 20	19/21			11/10	05/05						42/29		11/05		32/29	/24			

Figure 36. Occurrence of USCS soil types in limestone and dolomite

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 69/65															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/	10/15	01/01	/	/	/	08/09	72/35	/03	/03	16/29	/	/	03/12	/08



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	14/12	/	/	/	/08	/	/	/	14/08	57/33	/	/08	29/50	/	/	/	/
2-10	36/39	/	/	/05	06/	/	/	/	06/05	86/38	/03	/03	06/31	/	/	03/13	/08
10-20	14/18	/	/	29/11	/	/	/	/	14/11	71/11	/06	/	14/33	/	/	/28	/11
>20	14/15	/	/	29/13	/	/	/	/	14/07	43/20	/07	/	36/13	/	/	07/40	/13

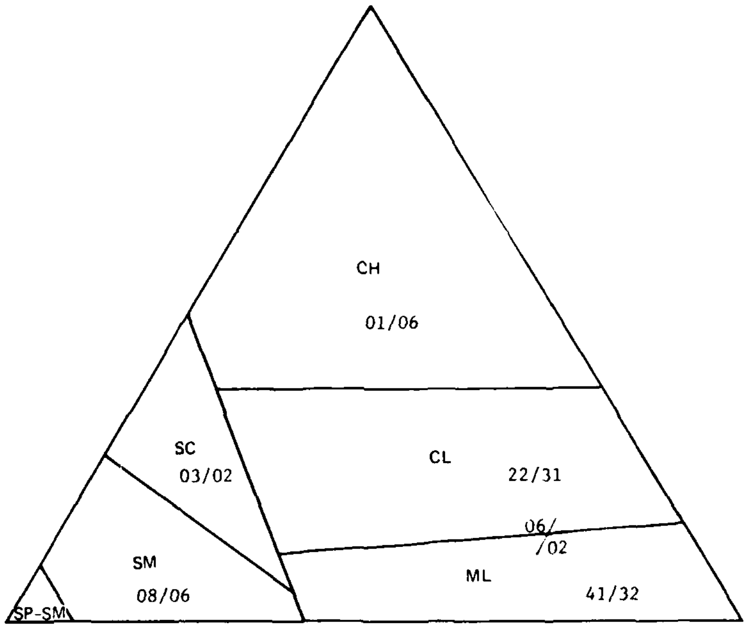
Figure 37. Occurrence of USDA soil types in limestone and dolomite

limestone soils. The figures included herein indicate that high percentages of silt and clay are common components.

211. Dolomite is very similar to limestone but contains varying percentages of Mg, which is always subordinate to Ca. Dolomite is harder and heavier than limestone but possesses the same physical characteristics. Generally, however, soils developed from dolomites are siltier and less plastic than those developed from limestone. Since the soils are very similar, they will not be dealt with separately in this report. Considerable mechanical deterioration of limestone results from swelling of included clays, especially montmorillonite in seams and inclusions.

212. Shale. The analysis considered 109 sites. Shales are composed predominantly of clay minerals (kaolinite, illite, and montmorillonite) and related minerals associated with muscovite, sericite, and biotite. Shale also contains tiny particles (mostly of silt size) of quartz and other resistant minerals, e.g., tourmaline, zircon, garnet, and monazite. Since quartz rarely occurs below silt size, shale will grade into siltstone as the quartz content increases. As previously stated, clay minerals and lime particles are sometimes deposited contemporaneously and calcareous shales or shaly limestones result. However, the lime is readily soluble and does not materially contribute to the composition of the residual soils that form from shales. Shale is brittle and exhibits a fissility roughly parallel to the bedding plane. It occurs in thin layers and is quite often interbedded with other sedimentaries such as siltstone, limestone, and sandstone. Oxidation of constituent metals such as iron pyrite can produce swelling and heaving and eventually cause physical breakdown of the rock. Thin-bedded shale will disintegrate more rapidly than thick-bedded or massive shale. A typical shale might contain 50 percent quartz silt, 35 percent clay minerals and mica, and 15 percent authigenic minerals. Exposed shale weathers easily and crumbles into small, thin plates which are an integral part of the incipient soil profile. The high silt content of shale is reflected by the dominance of clayey silt (ML) and silty clay (CL) in the 0- to 6-in. layer (Figure 38).

PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 200/222																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
01/	02/02	12/12	03/03		01/01		08/06	03/02	41/32	06/02	02/02		22/31	01/06			



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	24/31										63/48		04/03		33/45	/03			
2-10	151/173	01/	01/01	08/10	02/04		/01		05/06	02/03	48/31	2/2	02/05		30/31	01/07			
10-20	42/39		05/04	19/18	05/08		1/02		9/08	02/	40/24		/04		19/24	/06			
> 20	30/30		03/	27/33	03/10				07/07		43/20		03/		/20	13/10			

Figure 38. Occurrence of USCS soil types in shale

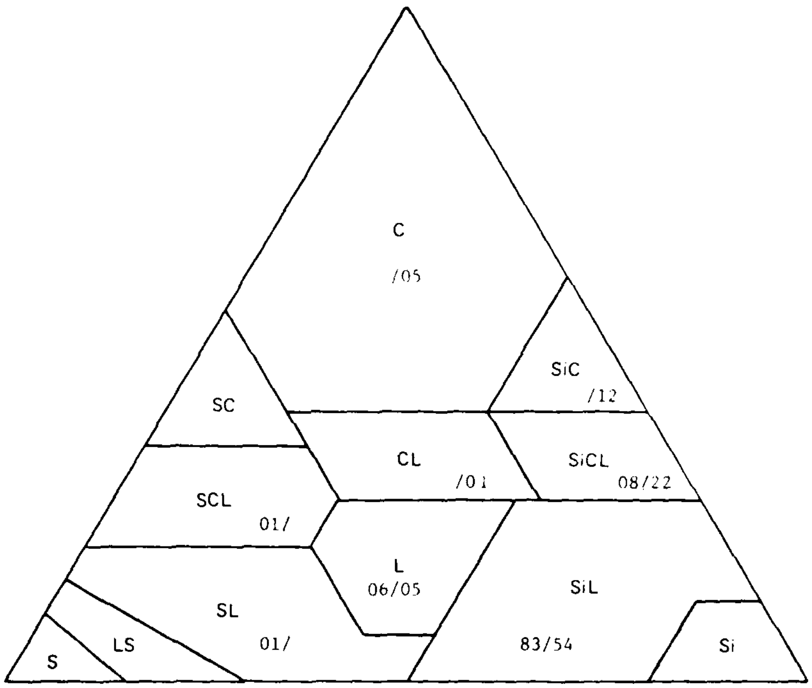
The gravel component in this layer is actually shale fragments in the process of decomposition. The clay component increases in the 6- to 12-in. layer as a result of the downward migration of the clay minerals and the soils become more plastic. The USDA histograms for both the 0- to 6-in. and 6- to 12-in. layers show that silt loam soils dominate (Figure 39). However, there is a marked increase in clay particles, as manifested by larger percentages of silty clay loam and silty clay soils.

213. Conglomerate. The profiles considered 15 sites. Conglomerate is a clastic sedimentary rock composed principally of gravel-size rocks but often with significant percentages of coarse sand, pebbles, and cobbles. Conglomerates usually have a matrix of sand or silt and may be cemented with calcium carbonate, iron oxide, clay, or silica. Metamorphosed, conglomerates are commonly altered to gneiss. The predominance of a particular size is often used as a modifier such as gravel conglomerate, pebble conglomerate, etc. The histograms suggest that coarse sand-size particles dominate most of the profiles and that the larger rocks are of gravel size. However, the USCS does not include sizes above gravel (Figure 40); reference to the USDA slope/grain size table will reveal significant quantities of stones, which increase with increase in slope (Figure 41). The cementing materials seem to be fine sands, silts, and clays. The percentages in the USDA table should not be interpreted to mean that a particular profile is 38 percent gravel (10 to 20 percent slopes), but rather that 38 percent of the total samples contained some gravel-size particles.

Glacial deposits

214. Glacial deposits are of subordinate interest in this report. However, study areas in the glaciated northern German plains afforded an opportunity to collected limited data. The following figures and tabulations are included for some residual soils that have formed on glacial deposits subsequent to their deposition during the Pleistocene period. Soils data were examined in the northern United States and northern Federal Republic of Germany for the following glacial landforms: (a) glacial outwash, which is stratified deposits, usually sand

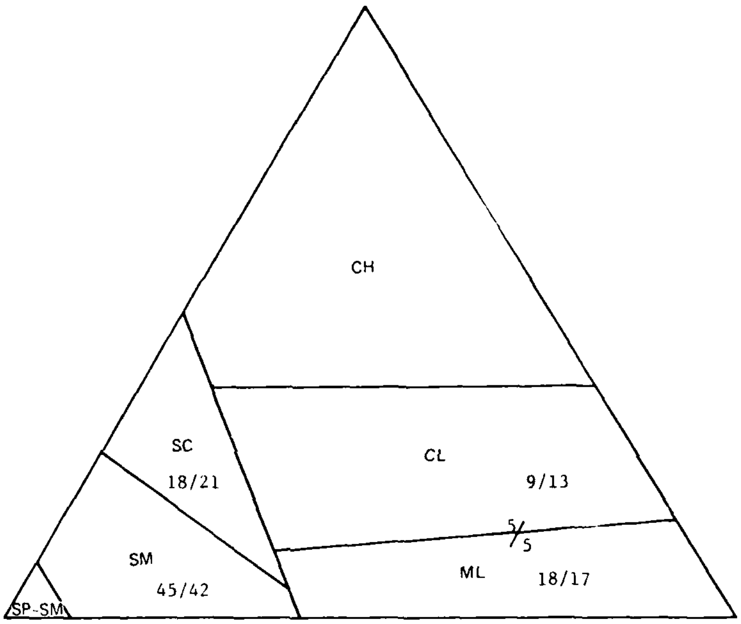
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN 6- TO 12-IN LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN/6- TO 12-IN LAYERS 109/129															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/101	30/29	04/02	01/01	/	/	01/	06/05	83/54	01/	/01	08/22	/	/	/12	/05



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	16/21	/	13/10	/	/	/	/	01/	/04	93/48	/	/	06/33	/	/	/14	/
2-10	82/84	/	18/25	/01	01/01	/	/	/	05/02	85/57	01/	/01	09/25	/	/	/07	/07
10-20	26/33	/	50/36	/	04/	/	/	/	08/	88/52	/	/03	04/27	/	/	/15	/3
> 20	19/18	/06	47/56	/	05/	/	/	/	16/	74/61	/	/06	05/11	/	/	05/17	/06

Figure 39. Occurrence of USDA soil types in shale

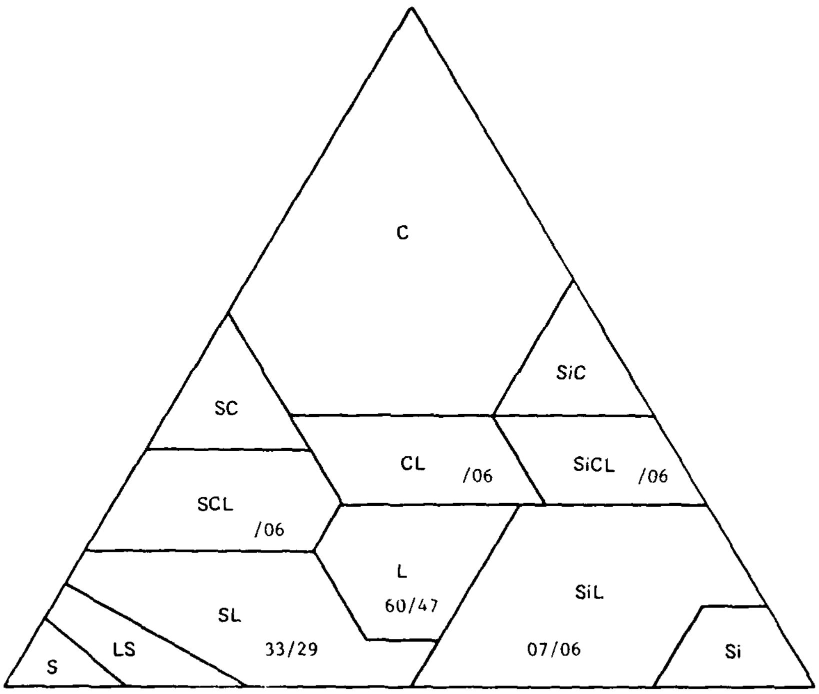
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN. 6- TO 12-IN. LAYERS 22/24																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
		05/08					45/42	18/21	18/17	05/05			9/13				



SLOPE PERCENT	NO. SAMPLES	PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																	
		USCS SOIL TYPES IN 0- TO 6-IN. 6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	1/1														100/100				
2-10	12/13			08/15					33/38	08/08	25/16	09/08			17/15				
10-20	12/11								50/45	25/36	25/18								
> 20	7/7								57/57	14/14	29/29								

Figure 40. Occurrence of USCS soil types in conglomerate

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 15/17															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
20/19	/	7/6	27/31	/	/	33/29	60/47	07/06	/06	/06	/06	/	/	/	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	1/1	/	/	100/	/100	/	/	/	100/	/	/	/100	/	/	/	/	/
2-10	7/9	14/11	/	14/11	43/33	/	/	/11	86/67	14/11	/	/	/11	/	/	/	/
10-20	8/8	38/38	/	/	/	/	/	50/38	50/50	/	/13	/	/	/	/	/	/
>20	6/6	50/50	/	/	17/17	/	/	33/33	67/67	/	/	/	/	/	/	/	/

Figure 41. Occurrence of USDA soil types in conglomerate

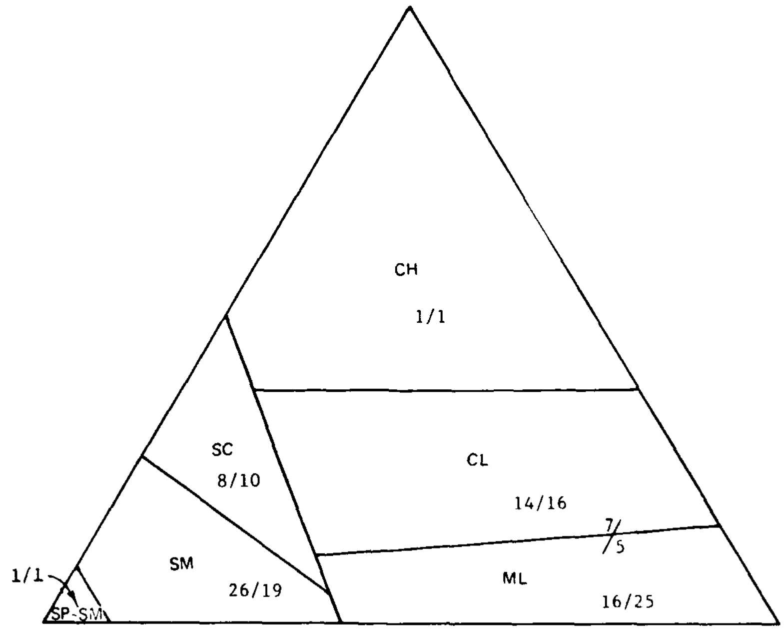
and gravel, that have been removed or "washed out" from the glacier by meltwater at the front or along the sides of the melting glacier; (b) glacial till, which is composed of unstratified drift deposited by the glacier and is a heterogeneous mixture of clay, silt, sand, gravel, and boulders of various sizes; and (c) glaciolacustrine, which is sediments deposited in lakes or topographic depressions by sediment-laden meltwaters emanating from the melting glaciers or ice sheets. These materials are generally silt- and clay-size particles.

215. Many glacial landforms occur in the northern Federal Republic of Germany and the northeastern and north central United States. These can be identified and delineated on large-scale topographic maps and photographs. Among these are moraines, outwash plains and terraces, former glacial lakes, eskers, kames, and drumlins. Each has a discrete association of engineering soils. An esker, for instance, has a geometry much like a meandering river and is a deposit left by an englacial or subglacial stream. It may reach tens of metres in height and range from 1 km to tens of kilometres in length. It is composed of roughly stratified sands and gravel. Sometimes eskers may become partly or wholly buried by subsequent advances of an ice sheet. Other glacial landforms may be less conspicuous than eskers, but may be identified by the skilled interpreter and assigned geometric and pedologic characteristics.

216. <u>Glacial outwash.</u> The analysis considered 94 sites. Examination of the USCS figures shows a dominance of sand and gravel soils. The soils are coarser the closer they are to the course, i.e., the melting glacier. The ML and CL soils are expected to be further away from the melting glacier than the SM and GM (Figure 42). Figure 43 shows a predominance of sand loam and loam soils, with 25 to 70 percent of the samples graveliferous. The graveliferous profiles show increase with increase in slope.

217. <u>Glacial till.</u> The analysis considered 302 sites. Till is heterogeneous material deposited by glaciers and reworked by meltwater from the glacier. Gravel, stones, and even large boulders are common occurrences. In the USCS, ML and CL soils occur most frequently, with SM soils occurring about 10 percent of the time (Figure 44). Sandy

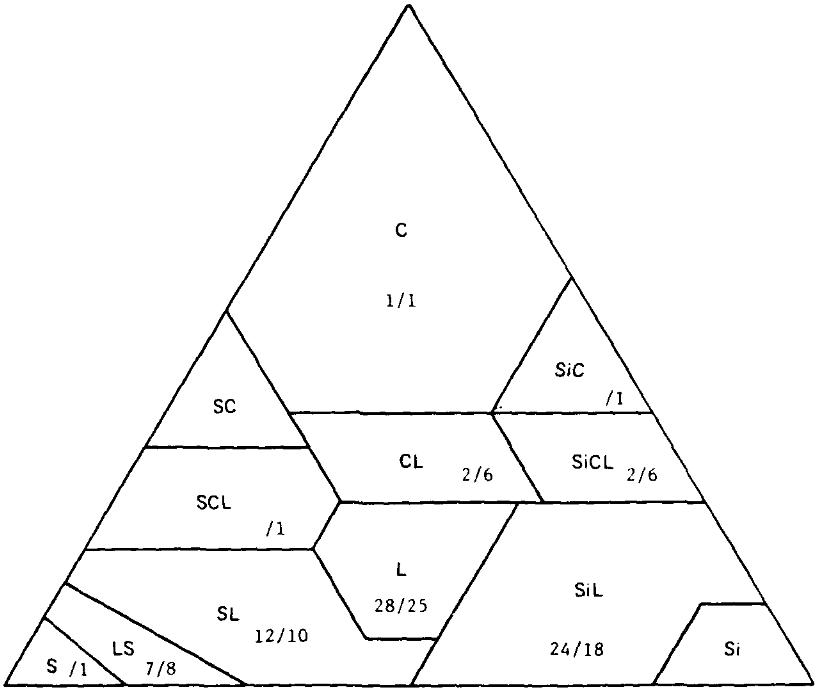
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 166/243																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
2/2	1/1	13/11	8/6	1/1	2/1	1/1	26/19	8/10	16/25	7/5	1/1	/	14/16	1/1	1/1	/	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
0-2	88/105	/	/	8/10	6/7	/	2/5	1/1	18/17	8/10	31/26	6/7	1/1	/	17/16	1/1	1/1	/	/
2-10	92/102	3/3	1/2	14/12	7/7	3/3	2/1	/	22/21	6/7	18/25	6/5	/	/	9/14	/1	/1	/	/
10-20	30/36	3/6	/6	10/11	3/3	3/6	/	/	33/19	3/11	37/2[illegible]	3/3	/	/	6/17	/	/	/	/
> 20	19/14	5/21	/	11/21	/	5/14	/	/	37/79	5/7	32/7	/	/	/	5/	/	/	/	/

Figure 42. Occurrence of USCS soil types in glacial outwash

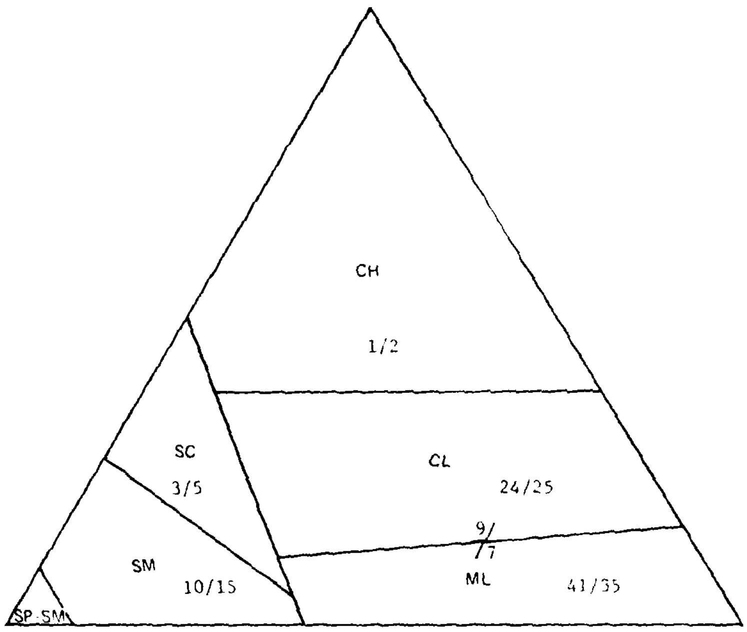
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 122/154															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/	1/1	24/24	/1	7/8	12/10	28/25	24/18	/1	2/6	2/6	/	/	/1	1/1



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	39/54	/	/	/	26/28	/2	8/9	18/19	26/20	38/30	/	3/4	5/11	/	/	/2	3/3
2-10	40/47	/	/	3/2	38/40	/	18/15	15/13	45/34	23/21	/	/11	/6	/	/	/	/
10-20	13/17	/	/	/	54/29	/6	8/12	15/6	69/41	/6	/6	8/24	/	/	/	/	/
>20	6/10	/	/	/	67/70	/10	/10	33/20	50/40	/	/	17/20	/	/	/	/	/

Figure 43. Occurrence of USDA soil types in glacial outwash

PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 547/680																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
		11/11	2/2		1/1		10/15	3/5	41/35	9/7	1/1		24/25	1/2	4/3	1/1	



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN. 6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH CH	CL	CH	OL	OH	Pt
0-2	222/186			2/1			1/		15/12	5/4	38/37	10/8	1/4		21/27	3/4	4/5	/1	
2-10	356/430			5/6	3/3				17/17	6/6	38/34	8/7	1/1		19/22	1/2	3/2	/1	
10-20	125/143			7/8	1/2		1/1		28/24	6/7	38/35	3/2			13/18	/1	2/1	1/	
> 20	87/78			7/12	/1		1/1		29/28	6/8	38/32	7/5			13/13				

Figure 44. Occurrence of USCS soil types in glacial till

loam, loam, and silt loam are by far the most frequently occurring USDA types, with silty clay loam showing a marked increase with depth (Figure 45). The USCS soil types show little change in the 6- to 12-in. layer.

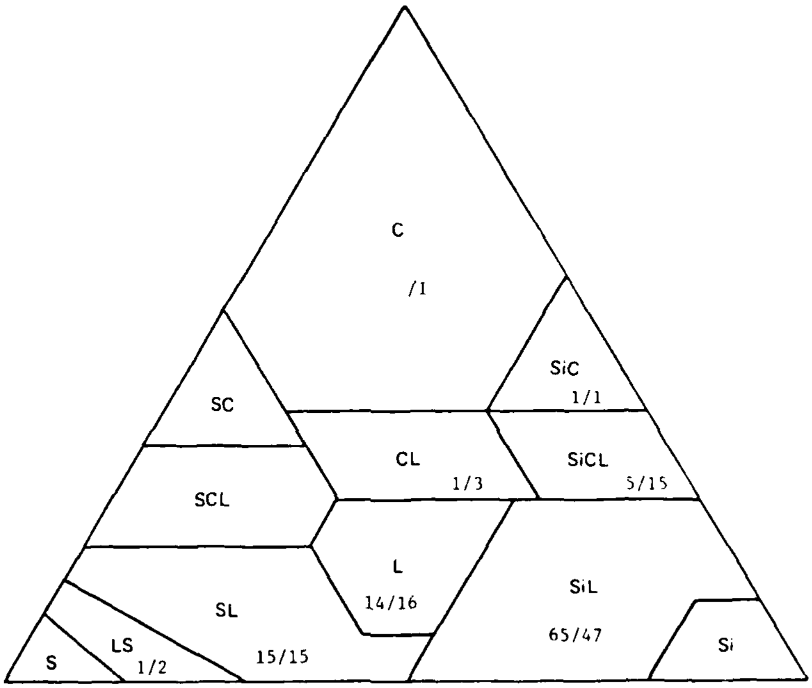
218. Glaciolacustrine. The analysis considered 111 sites. These deposits are usually varved seasonal layers; the silty or sandy component of which is deposited during the "summer," and the silty clay component during the "winter." Silt and clay are the dominant USCS soil types (ML and CL) with a slight decrease in grain size with increase in depth (Figure 46). Predominant USDA soil types are silt loam and silty clay loam with marked increases in silty clay and clay in the 6- to 12-in. layer (Figure 47).

Loess

219. The analysis considered 213 sites. Loess is a homogeneous, nonstratified, coherent, calcareous deposit of windblown silt, with subordinate amounts of fine sand and clay. It is generally accepted to have been deposited during the Pleistocene epoch when prevailing south-blowing winds removed the fine-grained component of glacially sorted unconsolidated materials. It is a common occurrence in the Mississippi River alluvial valley where it blankets terrace deposits, in eastern China, and north-central Europe. ML and CL are the predominant USCS soil types, with a slight decrease in grain size with depth as a result of leaching (Figure 48). The USDA data show nearly 90 percent silt loam in the 0- to 6-in. layer and increase from 5 to 40 percent silty clay loam in the 6- to 12-in. layer (Figure 49). There is a slight increase in the silt percentage with increase in slope.

220. In the Federal Republic of Germany, loess occurs principally on the north-facing flanks of the central highlands, where it blankets the slopes in varying thicknesses. The fine-grained materials composing the loess were derived from the north German glaciated plains. Special care must be taken to distinguish the loess from underlying residual soils on the mountain slopes. Where the areas are under cultivation, the loess and the underlying soil become mixed. The loess soils are considered among the most fertile in Europe.

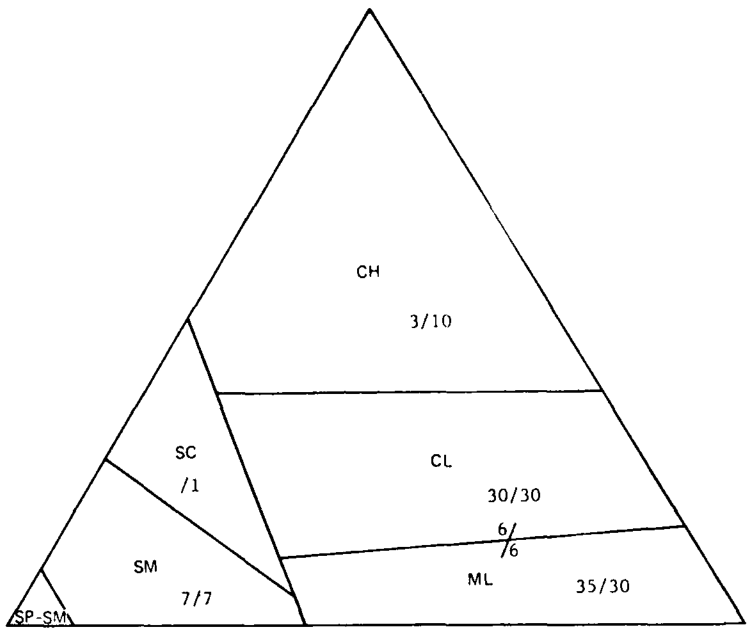
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN/6- TO 12-IN LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 310/390															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
2/2	2/2	3/7	4/6	/	1/2	15/15	14/16	65/47	/	1/3	5/15	/	/	1/1	/1



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	90/112	1/1	/	/1	4/4	/	1/3	8/13	9/10	67/46	/	/1	14/25	/	/	1/1	/2
2-10	167/237	3/2	2/4	13/8	5/8	/	1/1	15/18	15/17	69/48	/	/3	1/11	/	/	/1	/1
10-20	65/87	5/5	2/3	11/10	8/9	/	3/5	26/28	29/20	40/36	/	2/8	/5	/	/	/	/
>20	47/55	2/	/2	6/5	4/11	/	/2	23/35	38/22	34/25	/	4/13	/4	/	/	/	/

Figure 45. Occurrence of USDA soil types in glacial till

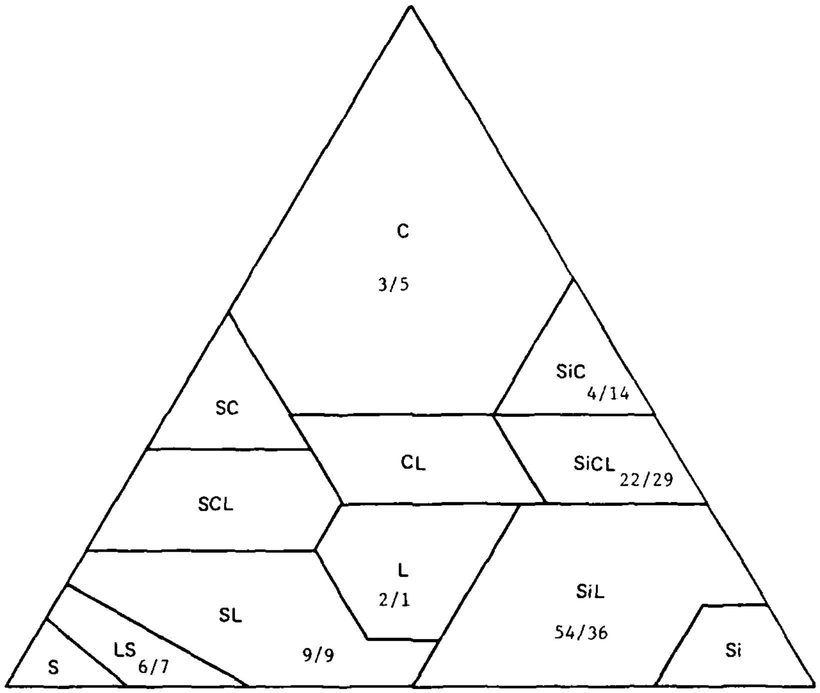
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN/6- TO 12-IN LAYERS 227/256																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	/	/	1/1	/	/	7/7	/1	35/30	6/6	5/5	1/1	30/30	3/10	10/8	2/2	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO. SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	138/163	/	/	/	/	1/1	/	/	7/6	1/1	33/27	7/6	4/6	1/2	28/29	4/12	12/9	3/3	/
2-10	71/84	/	/	/	/	/	/	/	10/10	/	38/36	7/7	4/5	/	30/30	1/6	7/5	3/2	/
10-20	9/8	/	/	/	/	/	/	/	11/13	/	33/39	/	11/	/	33/37	11/13	/	/	/
> 20	5/5	/	/	/	/	/	/	/	20/20	/	40/40	/	/	/	40/40	/	/	/	/

Figure 46. Occurrence of USCS soil types in glaciolacustrine

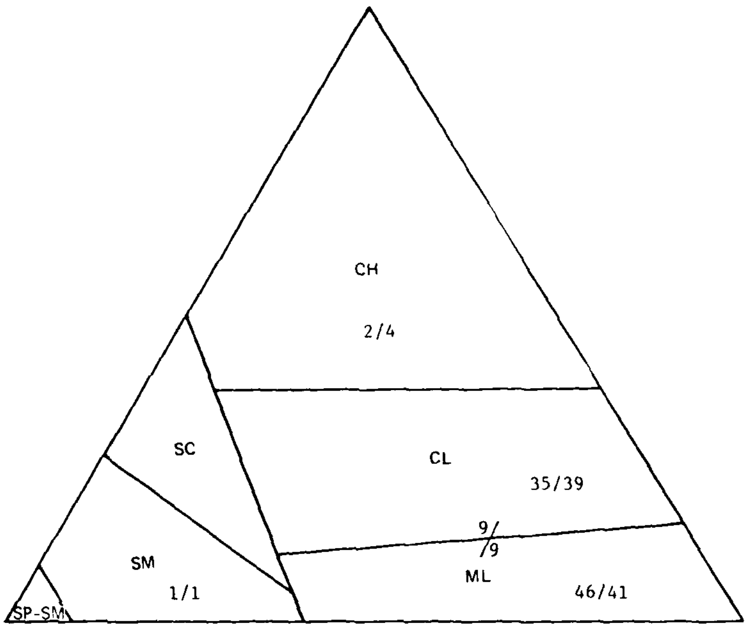
PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS: 113/152															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/	/	/	/	6/7	9/9	2/1	54/36	/	/<1	22/29	/	/	4/14	3/5



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	68/99	/	/	/	/	/	4/6	7/8	3/3	53/31	/	/1	24/32	/	/	6/14	3/4
2-10	38/51	/	/	/	/	/	8/6	13/10	/	55/44	/	/	18/24	/	/	3/12	3/6
10-20	4/4	/	/	/	/	/	/	/	/	75/75	/	/	/	/	/	/	25/25
>20	3/4	/	/	/	/	/	/	/	/	33/50	/	/	33/25	/	/	/	33/25

Figure 47. Occurrence of USDA soil types in glaciolacustrine

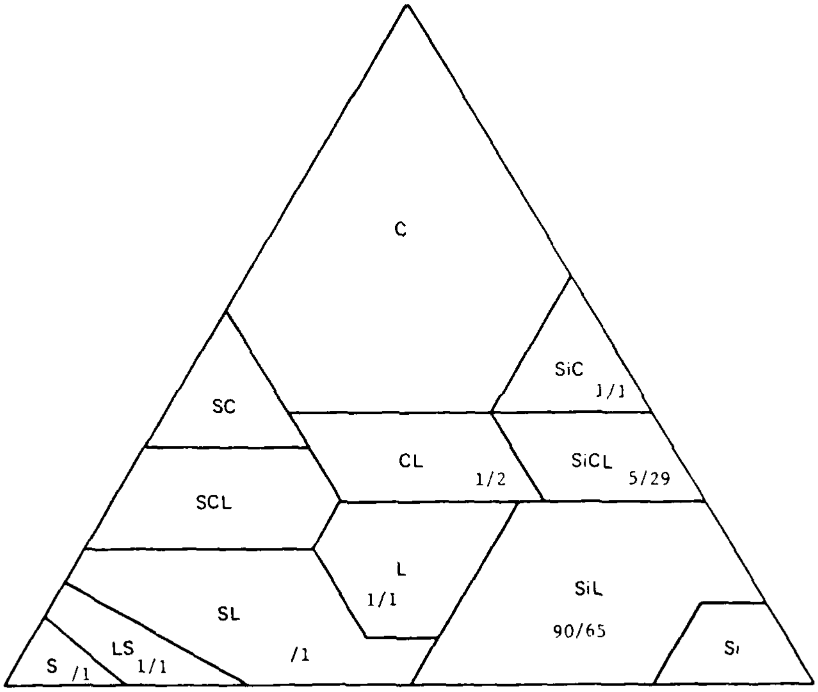
PERCENT OCCURRENCE OF USCS SOIL TYPES																	
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 385/386																	
GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
/	/	1/1	/	/	/	/	1/1	/	46/41	9/9	1/1	/	35/39	2/4	2/3	2/2	/



PERCENT OCCURRENCE OF USCS SOIL TYPES BY SLOPE CLASS																			
SLOPE PERCENT	NO SAMPLES	USCS SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS																	
		GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML CL	MH	MH-CH	CL	CH	OL	OH	Pt
0-2	139/156	/	/	/	/	/	/	/	1/	/	45/40	9/8	1/8	/	35/38	4/6	3/3	3/3	/
2-10	148/184	/	/	/	/	/	/	/	1/	/	54/44	10/9	/	/	31/40	2/4	2/2	2/1	/
10-20	52/42	/	/	2/	/	/	/	/	4/7	/	63/52	6/2	/	/	25/38	/	/	/	/
> 20	27/33	/	/	4/	/	/	/	/	4/6	/	67/48	4/3	/	/	22/42	/	/	/	/

Figure 48. Occurrence of USCS soil types in loess

PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES															
USDA MODIFIERS AND SOIL TYPES IN 0- TO 6-IN./6- TO 12-IN. LAYERS															
NUMBER SAMPLES IN 0- TO 6-IN./6- TO 12-IN. LAYERS 225/258															
ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
/	/	1/1	/	/1	1/1	/1	1/1	90/65	/	1/2	5/29	/	/	1/1	/



PERCENT OCCURRENCE OF USDA MODIFIERS AND SOIL TYPES BY SLOPE CLASS																	
SLOPE PERCENT	NUMBER SAMPLES	MODIFIERS 0-6 IN./6-12 IN.				USDA SOIL TYPES IN 0-6 IN./6-12 IN. LAYERS											
		ST	SH	CH	GR	S	LS	SL	L	SiL	SCL	CL	SiCL	Si	SC	SiC	C
0-2	76/80	/	/	/	/	/	1/	/	/	89/80	/	/	8/18	/	/	1/2	/
2-10	104/129	/	/	/	/	/1	1/1	/	/1	95/62	/	1/2	3/33	/	/		/
10-20	32/42	/	/	/	/	/	3/	/1	3/2	94/69	/	/2	/24	/	/	/2	/
>20	19/19	/	/	5/3	/	/	/	/	/	100/94	/	/	/21	/	/	/5	/

Figure 49. Occurrence of USDA soil types in loess

221. The statistical analysis considered 213 sites.

Comparison of United States and Federal Republic of Germany Soils

222. During the 1978 and 1979 field programs in the Federal Republic of Germany, a total of 180 sites were sampled in the various study areas to determine the relationships between parent materials, viz., rocks, and the associated soil profiles. A tabulation of these relationships is presented as Figure 50. Unfortunately, most data presented in this tabulation are too few and geographically scattered to enable meaningful comparisons. Soils at many of the sites were shallow with numerous rock fragments. This was especially true of the shale samples. Where profiles were shallow, it was not possible to sample the 6- to 12-in. horizon. This fact is reflected in the disproportionate number of 0- to 6-in. samples as opposed to those from 6 to 12 in. The classifications were performed using field techniques only. There were only a few laboratory tests made to verify the field classifications.

223. It will be remembered that all the data shown in Figures 10 through 49 were from United States sites. In order to obtain an early, albeit tentative, assessment of the agreement or lack thereof between United States and Federal Republic of Germany soils derived from the same origin, a limited comparison was made. The comparison consisted simply of listing the predominant soil type for origins considered to be reasonably analogous in the two countries in the judgment of the author. Such a list is given on page 133.

224. A careful examination of the data in the following tabulation, while revealing no perfect agreement in both soil type and percent occurrence for the same origin and layer, shows at least that there were no wide disparities. Note, particularly, that loess and sandstone were consistent as to soil type, differing only in percent occurrence. It was concluded that this initial assessment of the accuracy of predicting soil type by analogous means is sufficient to merit the continued study of this technique, i.e., the methodology developed in this study, and its current employment in the absence of ground truth or remote sensing data.

Origin	Number of Samples 0- to 6-in. Layer/ 6- to 12-in. Layer	Percent Occurrence of USCS Soil Types, 0- to 6-in. Layer/6- to 12-in. Layer GW	GP	GM	GC	SW	SP	SP-SM	SM	SC	ML	ML-CL	MH	MH-CH	CL	CH	OL	OH	Pt
Granite	3/3	5/	5/	5/	5/					33/33	33/33				33/33				
Basalt	20/14				10/			5/7		25/28	/7				45/44	15/14			
Quartzite	4/2			50/50			25/		/25						25/25				
Slate	1/1											100/100							
Marl	4/4										25/25				50/25	25/50			
Sandstone	72/61			1/		/1	7/		72/77	7/5	4/7				6/10	3/			
Limestone	18/15				6/				11/7		11/20				39/33	33/40			
Dolomite	6/5				17/										66/60	17/40			
Shale	8/7				50/					/14	12/14				38/72				
Graywacke	1/1				100/										/100				
Glacial outwash	13/12			8/			69/50		23/38	/12									
Glacial moraine	9/8			11/12		11/		78/75	/13										
Glacial ridge	3/2					100/100													
Glacial (undifferentiated)	2/1				50/				50/100										
Loess	17/12									77/67	17/17				6/8	/8			

Figure 50. Percent occurrence of USCS soil types, Federal Republic of Germany - 1978 and 1979

Origin	Predominant Soil Type/Percent Occurrence			
	United States		Federal Republic of Germany	
	0- to 6-in.	6- to 12-in.	0- to 6-in.	6- to 12-in.
Granite	SM/43	SM/25	SC, ML, CL/33	SC, ML, CL/33
Basalt	ML/48	ML/38	CL/45	CL/43
Quartzite	SM/27	SM/40	GM/50	SM, CL/50
Slate	ML/24	ML/25	ML-CL/100	ML-CL/100
Sandstone	SM/34	SM/31	SM/72	SM/77
Limestone	ML/46	CL/36	CL/46	CL/40
Shale	ML/41	ML, CL/32	CL/36	CL/29
Glacial Outwash	SM/26	ML/25	SP/69	SP/50
Loess	ML/46	ML/41	ML/82	ML/67

PART V: METHODOLOGY

225. This part describes the methodology developed in this study to predict soil texture by application of the interrelations among genetic factors, natural and cultural processes, and soil formations, discussed in Parts II and III, in combination with the rock-soil relations, discussed in Part IV. It is assumed that a prediction of soil texture is to be made for Area X, that Area X is environmentally analogous to the area from which the statistical data in this study were derived, and that these data are statistically significant.

Genetic Factor-Soil Formation Relations

226. The following is a review listing of the genetic factors known to influence soil formation. The factors are listed in the relative order of the importance of their effects on the evolution of soil texture, according to the judgment of the author.

Geology

227. Variations in lithology within rock units can profoundly affect the texture of the weathered soil.

Climate

228. Local climatic changes often significantly alter the composition of residual soils weathering from identical parent rocks.

Topography

229. Topography is important in the sense that the relative position on the topographic profile influences both the depth and texture of the soil profile.

Time

230. The period of (geological) time that a soil undergoes weathering will affect its textural characteristics to some degree.

Biological activity

231. Biological activity promotes rock decay and thus influences the textural character of the soil.

Rock-Soil Relations

232. The following is a list of the rock types in this study for which statistical data on residual soils occurrence are presented in Part IV. The figure numbers showing the corresponding statistical data (graphics and tables) are given, for convenience:

Rock Type	Figure No.
Granite	10 and 11
Diabase	12 and 13
Granodiorite, quartz monzonite, and quartz diorite	14 and 15
Gabbro	16 and 17
Basalt and andesite	18 and 19
Rhyolite	20 and 21
Gneiss	22 and 23
Schists	24 and 25
Quartzite	26 and 27
Serpentine	28 and 29
Slate and phyllite	30 and 31
Siltstone	32 and 33
Sandstone	34 and 35
Limestone and dolomite	36 and 37
Shale	38 and 39
Conglomerate	40 and 41

The Methodology

233. The methodology developed in this study is essentially covered in detail in the discussion under Parts II, III, and IV, at least by inference. In this Part the methodology is brought into sharper focus, mainly through the use of examples showing how the methodology might be employed.

Minimum data available

234. Assume that the only knowledge that the analyst has concerning Area X is that the soil was formed in place (a residual soil) from a specific rock type. Under this condition, the method for predicting soil texture is simple and direct: the analyst merely extracts data from the appropriate figures shown in Part IV and applies them to Area X.

235. For example, assume granite to be the rock type in Area X. From the granite data (Figure 10) for USCS soils, the following typical information can be read:

- a. Granite soils in the 0- to 12-in. layer covered a wide range, from GM (silty gravels) to fat clays (CH). (See Figure 1 for explanation of symbols.)
- b. The two most dominant soils in the 0- to 6-in. layer were SM (43 percent) and ML (26 percent).
- c. The two most dominant soils in the 6- to 12-in. layer were SM (25 percent) and SC (18 percent).

236. More specific information on the textural and plastic attributes of soil can be obtained by reference to the USDA soil classification triangle (Figure 2) and the USCS chart (Figure 1). For example, since the predominant USDA soil is sandy loam (SL) and this was shown above to be SM in USCS terms, reference to the triangle showing predominant USCS soil types superimposed on a USDA textural triangle (Figure 3) shows the approximate centroid of the area common to SL (USDA) and SM (USCS) to be 71 percent sand, 18 percent silt, and 11 percent clay. Note that sand, silt, and clay are in USDA terms (see Figure 3). Reference to Figure 1 would indicate that the soil was not plastic, and this would indicate to the analyst that vehicles moving in this area would not be plagued by sticky soils tending to jam the running gear.

Addition of slope data

237. If, in addition to the minimum data specified above, the slope of Area X were known, further refinements of the prediction could be made, as illustrated by example in the following paragraphs.

238. Example. Consider only the 0- to 6-in. depth and the USDA

classification. Examime the table showing the distribution of USDA soil types by slope classes in granite (Figure 11).

239. It is noted (from examination of Figure 11) that the USDA soil shown to be dominant when all slopes were considered was SL (81 percent), but that SL does not even appear as a soil type in the 0- to 2-percent slope class. To arrive at a texture for the 0- to 2-percent range, the analyst would note that the soils were evenly distributed into three classes, L, SCL, and CL. He would further note that in USCS terms the samples available showed 50 percent SM and 50 percent ML (Figure 10). He might then look for a representative point in Figure 3, i.e., a point common to the area represented by the soil types (USDA and USCS) quoted. In the author's judgment, this would be approximately 50 percent sand, 40 percent silt, and 10 percent clay. Note the very poor agreement between USDA and USCS types in this case and therefore the doubt that is cast on the accuracy of prediction in this case. Nevertheless, the analyst would be reasonably sure the soil in the 0- to 2-percent range was significantly finer than the predominant soil, considering all slopes, and make the allowance for this in his mobility assessments. It is noted that no gravel appears in the 0- to 2-percent range.

240. At 2- to 10-percent slopes, the two most dominant USDA soils comprise 58 percent of the total, sandy loam (SL) occupies 33 percent, and loam (L) 25 percent. According to the USCS, the two most dominant soils are SM (42 percent) and ML (29 percent). Using this observation (and Figure 3), the analyst might estimate the texture to be roughly 60 percent sand, 30 percent silt, and 10 percent clay, a coarser soil than that at 0- to 2-percent slope but finer than the "average" soil. It is noted that 10 percent gravel occurs in the 2- to 10-percent range and that the presence of gravel increases (one sign of a coarser soil) to 50 percent on slopes greater than 10 percent.

241. Other examples. Many other permutations of the slope range and USCS and USDA soil data shown herein are obviously possible, but those shown are considered sufficient as examples to illustrate the methodology for predicting soil texture offered herein. The examples

also demonstrate the flexibility and open-endedness of the model.

Employment of genetic factor-cultural processes-soils relations to texture predictions

242. The accuracy of soil texture predictions can be enhanced when certain additional information on genetic factors and cultural practices is known. The employment of genetic factor-cultural processes relations is not necessarily a "third step" in the methodology, as might be inferred from the order of presentation herein. The good analyst will be constantly aware of the potential of these relations during the analysis or prediction stages.

243. The following examples are purposely generalized. It should be reiterated that the evolution of soil is the result of the complex interaction of all of the soil-forming factors.

244. Geology. If it is known only that the predominant rock type in a region is shale, then reference to Figure 38 will reveal that the most frequent soil type is ML (USCS). However, if additional information at a specific location reveals the rock is a clay shale (which characteristically has less than 10 percent silt), then it can be deduced that the resulting soil will be clay, either CL or CH.

245. In the Federal Republic of Germany, sandstone soils were observed in a limited region and displayed little lithologic variation. The soils were classified almost without exception as SM (USCS). However, examination of Figure 34 reveals a much wider diversity of soil types, reflecting broader lithologic variation. If it was known, for example, that the sandstone was conglomeritic, the analyst might be justified in predicting the soil to be GM instead of SM.

246. Climate. For a region of hills known to be composed of granite rock, reference to Figure 10 would indicate the most common soil type to be SM (USCS). However, if it was known that a portion of this region at, say, a higher elevation received more rainfall (for example, twice as much) than the total area, then it might be deduced that the soils here are in a more advanced stage of weathering and are of a finer texture, probably CL.

247. Culture. From the tables the occurrence of soil types derived from a particular rock type can be predicted for a certain range of slopes. These largely reflect natural conditions. If it is known further that the slope is cultivated, then it can be predicted that the distribution of soil textures in the 0- to 6-in. and 6- to 12-in. layers will be changed somewhat, since the soils have been mixed by plowing. Thus, the 0- to 6-in. layer will become finer in texture and the 6- to 12-in. layer coarser in the cultivated areas than in the natural ones.

248. In agricultural areas, contour plowing has greatly reduced erosion due to runoff that might otherwise occur. This has resulted in a greater percentage of the fines in the soil remaining in place. Where these precautions are not taken, i.e., natural conditions, appreciable fines might have been displaced and the overall texture of the soil altered.

Summary of significant points in discussion of methodology

249. It is considered that the discussion and examples above warrant the statement of certain points, as follow:

a. The methodology developed herein is philosophically based on the proposition that similar genetic factor-natural processes relations produce similar soils. The success of the methodology will be a direct function of the quality of the data available. In particular, the need for statistically valid and significant rock type-soil type relations in given climates is vital.

b. The methodology offered is flexible and open-ended, suggesting that a final methodology, i.e., an acceptable system for predicting values for all pertinent terrain parameters that is flexible and open-ended, is feasible.

c. Good judgment is necessary in applying the methodology.

d. Application of the methodology to the minimum data condition requires only a statistical representation of soil type.

e. Addition of slope data to the minimum data condition complicates the methodology and reinforces the need for good judgment on the part of the analyst, but enhances the accuracy of soil texture prediction.

f. The coarser soil resulting from an increase in slope is in conformance with genetic factor-soil formation relations discussed in Part III of this report.

g. Application of known interrelations among genetic factors, natural and cultural processes, and soil formations by a qualified analyst is a bona fide means of predicting soil texture.

PART VI: CONCLUSIONS AND GENERAL DISCUSSION

250. The specific conclusions resulting from this study and a brief discussion of some generally related topics are presented in this part of the report.

Specific Conclusions

251. It was felt that this study, admittedly limited in scope and in the nature of a pilot study, warranted the following conclusions:

- a. A methodology for predicting the texture of residual soils in humid temperate climates was developed based on well-known relationships among genetic factors, natural and cultural processes, and soil formations and reinforced by the examination of rock-soil type data specifically obtained for this study.
- b. The methodology appears to be practicable, although it is not quantitative in all its aspects and will require good judgment on the part of the user.
- c. The methodology is flexible and open-ended. It appears applicable, in principle, to other soil categories, e.g., glacial and aeolian, to other climates, and to other terrain parameters, e.g., vegetation. It is amenable to techniques for improvement in its ease of application and accuracy and is capable of using data from diverse sources.
- d. The methodology, while simple in its basic aspects, cannot be reduced to mindless, mechanical steps. Success in the results of application of the methodology will vary directly with the amount and quality of input data available and the knowledge, experience, skill, and judgment of the applier of the methodology.
- e. It should be recognized that one cannot expect a totally accurate prediction of the discrete soil texture that occurs at a given remote spot using the analogy principles embodied in the subject methodology (or any conceivable similar one). This is evident when one realizes that soil samples taken only a few feet apart often exhibit different textures. Nevertheless, the methodology is regarded as a useful tool in the absence of opportunity to collect ground truth or remote sensing data.

General Discussion

252. The work required to fulfill the specific purpose of this pilot study inevitably prompted the author to the consideration of related interdependent subjects. Some of the more important of these are discussed in brief terms in the following paragraphs.

Interaction of natural processes

253. Many residual, glacial, and loessial soils are the net result of the interaction of two or more natural processes. The resulting landscapes and associated soils do not always conclusively reflect the individual contributions of each process. For example, colluvial or alluvial processes may leave surficial deposits of transported sediments overlying residual soils. Another example occurs when modern rivers traversing glacial terrain overflow during cyclic flooding and leave a thin veneer of alluvial sediment. Over a period of years this cyclic sedimentation may build up a surface layer of appreciable thickness.

Effects of short-term climatic regimes

254. Short-term climatic regimes may significantly impact upon the formation of residual and glacial soils, accelerating in one instance and deterring in another. Even variations in modern climates from one region to another impact upon the evolution of soils with the result that they may reach a state of maturity in one area much sooner than another, even though parent material and topography are identical.

Level of parameter detail

255. It has yet to be demonstrated whether the level of detail required of mobility parameters can be predicted in geomorphologically analogous landscapes in the same climatic regime by the extrapolation of parametric data from a measured site to others remote and unmeasured. This stresses the need for identifying and evaluating genetic factors at every sample site. If these genetic factors evaluated at remote sites are within specified levels of accuracy, then predictions of class ranges of parametric factors values should be feasible.

Effects of source materials
on evaluation of genetic factors

256. The terminology, reliability, and level of detail of source material for a study area have a profound effect upon the evaluation of genetic factors that collectively control the mathematical limits of a terrain parameter. They also affect the identification and delineation of geographic areas in which natural processes are interacting with the genetic factors to produce the terrain factor to which the parameter has a direct and technological relationship. Specifications as to the nature of the source cannot and should not be rigidly established. Rather, they should be flexible and open-ended, accommodating general data at one extreme and specific data at the other. It is doubtful if any quantitative assessment of the relationship between the level of accuracy and detail of the source material and the level of predictability of terrain parameter values can ever be formulated. This is due largely to the diversity in source materials, not only from one country to another, but also from one study area to another within the same country.

Identification and delineation
of areas of active processes

257. Areas where processes are currently active or have been active during the Quaternary and late Tertiary periods can be identified and delineated on large- and medium-scale topographic maps and aerial photographs and medium- to small-scale geologic maps, for various climatic regions. It is desirable first to get a general physiographic overview of the study area to determine component environments and their associated landforms and to select, on the basis of this analysis, areas for detailed study. However, since most detailed study areas are selected because of military priority, the generalized physiographic overview will provide some basis for establishing the representativeness of the selected areas.

Guidance for parametric prediction

258. Guidance should be provided to establish general guidelines that will enable personnel of different scientific disciplines to identify areas where the interaction of natural processes and genetic

factors produce soils that can be identified in terms of mobility-related parameters, e.g., soil type and soil moisture. Similar procedures using this general guidance should be developed for other terrain factor parameters, e.g., obstacles.

Recognition of natural and cultural processes

259. Within a given climatic zone, natural and cultural processes can be recognized if the general geology, topography, and cultural practices indigenous to a particular country are known. As the map scale increases, the delineation of areas of homogeneous terrain parameter values generally becomes more definitive. A scale of 1:50,000 is considered acceptable and is sufficient for the delineation of genetic factors and natural processes areas. A major problem with mapping at this scale is the enormous effort that would be required in a large study area as a result of the large number of map sheets that would be required. The largest universal (world) topographic map coverage is 1:250,000 and coupled with available geologic and land use maps would enable delineation of gross genetic factors and major areas where processes are currently active or have been during the Quaternary (600,000-year) period. The 50- or 100-m contour interval used in preparing these maps would result in many natural processes going unrecognized.

The role of climate on soil formation

260. The role of climate varies significantly with latitude in its influence on soil formation. In arctic climates, the formation of soil is minimal due to perennial ice and snow cover, or nonexistent, while in humid tropical areas because of continuously high temperatures and rainfall, weathering processes are maximal. In humid temperate climatic zones weathering reaches a maximum during the warm, rainy summer months, while chemical weathering during the winter months is retarded because of cold temperatures and snow cover. Within a single climatic zone the role of cultural practices will be proportionate to the degree of development. For instance, in the Federal Republic of

Germany, a highly developed industrial and agricultural country, cultural practices are more dominant than in most other European and Asian countries.

Development of modern landforms

261. Modern landforms have in some instances developed under climatic regimes differing from those currently active. The landforms, although created during a previous geologic epoch (Pleistocene), are being modified by current natural and cultural processes.

Internal variation within landforms

262. Landforms occurring in areas characterized by a relative consistency of genetic factors may exhibit significant internal variation in the type and distribution of soils. For example, an alluvial terrace may consist of relict alluvial deposits ranging in grain size from gravel to clay. Only a skilled photointerpreter with large- to medium-scale aerial photographs could identify the component landforms and environments of deposition. Without photography in this case, the collection of ground truth data would be an arbitrary process.

263. Local variations in landform expression will always occur, but in most cases if the controlling genetic factors are known in sufficient detail, terrain parameters are predictable. Just how to deal with the exceptions is not clear at this time. If they are unpredictable, then their presence and characterization cannot result from the analysis of source material and can only result from ground truth. If the local variations cannot be tied to a detailed combination of genetic factors, then the extrapolation of the ground truth is impossible. Since these are mainly microgeometry variations, a surface roughness index may be used for individual variations.

Process stages

264. Stages in which some processes are active are important in that at different stages terrain will display dissimilar characteristics. Regarding alluvial processes, degree of dissection is a good example in that it affects stream density, the relationship between stream valleys and interfluve areas, and the cross-section characteristics of stream channels. All of these parameters are affected by the nature of the

soil or rock in which the pattern is actively eroding and the amount and distribution of rainfall. In fact, recognition of drainage patterns on maps and aerial photography is a useful interpretation key in the identification of the material being eroded. Since both process and stage must be determined from maps and aerial photographs, the scale again becomes the limiting criterion. While the contour interval on even large-scale topographic maps may preclude the recognition of small drainage features, they are usually recognizable on photographs of the same scale.

Effect of cultural patterns

265. Cultural patterns, such as agricultural, managed forests, and other land use patterns, can significantly affect not only vegetation parameters but also soil texture and distribution, surface microgeometry, and minor drainage parameters. Cultural influences in local geographical situations are difficult to assess without knowledge of indigenous practices. For example, a floodplain in Southeast Asia would likely be devoted to rice cultivation with orchards occurring along the natural levees. A floodplain in the United States in a similar climatic zone might support such crops as cotton, soybeans, and corn, with sugar cane growing on the natural levees.

266. Often short-term cultural practices may completely override an active natural process which may have been in progress over an extended period of geologic time. Cultivation on a slope undergoing long-term erosion may significantly alter the effects of time.

Influence of man

267. The influence of man may impose restraints on natural processes or expedite them, depending on the particular circumstance involved; e.g., terracing along hill slopes disrupts surface drainage, while the wanton cutting of timber in other areas may cause severe erosional problems, thus initiating a short-term process in an otherwise stable environment. Even the surface microgeometry of a landform may change by the leveling practices associated with cultivation.

Level of genetic factor detail

268. Parametric class values for a particular mobility study

will dictate the level of detail with which it is necessary to characterize the genetic factors which work together to create a particular terrain condition. However, the level of detail is not always a matter of choice but is largely dependent upon the quality and availability of source materials.

Indicator factors

269. Some mention should be made of indicator factors that may not relate directly to a particular terrain parameter but may indirectly facilitate the determination of a factor having a direct relationship with the parameter. Drainage patterns observed on aerial photographs may identify the structure and lithology of a topographic high and thus permit, along with the evaluation of other genetic factors, a prediction of the soil texture parameter. Certain types of vegetation are indicative of waterlogged ground conditions and portend organic soils, while other types relate to the groundwater table and thus might provide useful information in determining the soil moisture parameter. In acquiring information on genetic factors in the field, it would be a useful adjunct to consider indicator factors.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

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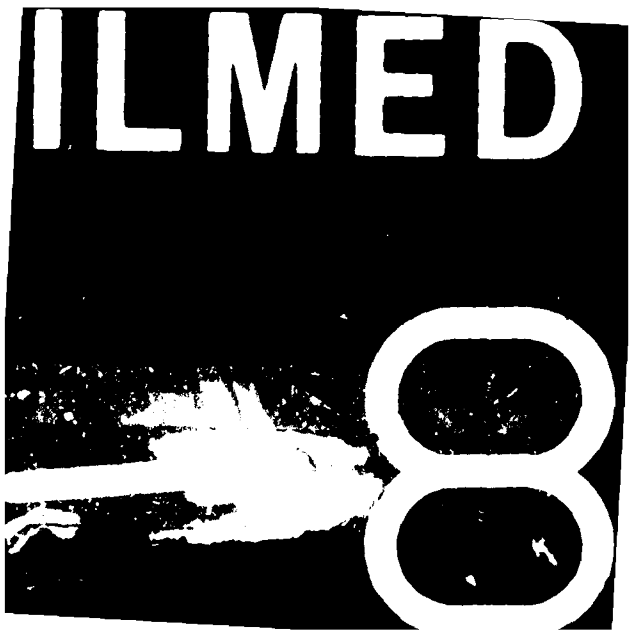
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